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URANINITE AND THUCHOLITE FROM PIED DES MONTES, CHARLEVOIX COUNTY, QUEBEC

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INTRODUCTORY

The brief notes given below on the character and occurrence of uraninite and thucholite at the Pied des Monts mine are based on a visit paid to the property in October, 1936, and on a rather superficial study of a suite of specimen material secured on that occasion.

Two good specimens of the uraninite and one of the thucholite were sent to Dr. A. C. Lane, in 1937, as a contribution to the work of his Committee on the Measurement of Geologic Time, and one of the uraninite pieces was turned over by him for investigation and analysis to O. B. Muench, whose report has been published (*Jour. Am. Chem. Soc.*, **61**, 2742, 1939).

Muench's results showed a lead-uranium ratio of $6.67/49.25 = 0.135$. There was a rather high ignition loss of 12.07 per cent, due probably to the thucholite content, as indicated by the radiographs accompanying this paper. Noteworthy was the almost complete absence of thorium and rare earths, a feature that makes this uraninite exceptional among those of which analyses have been published. The calculated age is 956 million years.

Muench's analysis gave rather different figures for uranium and lead as compared with those obtained by Ellsworth (see footnote reference 6) on a specimen previously analyzed by him, which yielded a lead-uranium ratio of $10.84/73.08 = 0.148$. Ellsworth notes that his specimen was very fresh, with no evidence of alteration, and presumably it contained far less thucholite.

The lead extracted by Muench was sent to A. O. Nier, at Harvard University, for the isotopic determination, the result of which showed¹

* Bureau of Mines, Department of Mines and Resources of Canada. Submitted with the approval of the Director, Mines and Geology Branch.

¹ Nier, A. O., The isotopic constitution of radiogenic leads and the measurement of geological time: *Physical Review*, **55**, No. 2, 158-159 (1939).

about 4 per cent to be common lead. The age calculated from AcD/RaG was 905 million years, and from RaG/U²³⁸, 882 million years.

DESCRIPTION

The two matrix specimens of uraninite, and the single specimen of nodular thucholite associated with it, from the old Pied des Monts mica mine, in Lacoste township, Charlevoix County, Que., which I gave to Dr. Lane early in 1937, formed part of a small mixed lot of these minerals which I obtained in 1936. The pegmatite from which they came is the old, classic locality from which J. Obalski, many years ago, obtained similar material, and which he described briefly in *Mining Operations in the Province of Quebec for the Year 1903*, a publication of the Quebec Department of Lands, Mines and Fisheries, pp. 65-68, as well as in *Journal of the Canadian Mining Institute*, 7, pp. 245-256 (1904). Obalski's description was based on reports made on the uraninite (cleveite) by Rutherford, then at McGill University, and by the Curies, in Paris.

The location of the deposit, as near as I can state it, is 70° 20' W. and 47° 45' N., about 100 miles below Quebec city, on the north shore of the St. Lawrence. It lies 13 miles north of the end of the branch railway leading from Murray Bay to La Chute, on the Murray River, and one can drive by car to within 2½ miles of the mine.

Opened originally for muscovite mica by a French company in the early years of the century, the property subsequently lay idle until 1935, when it was acquired by Quebec interests, the Syndicat Charlevoix Radium Exploration, who have since done intermittent work for both mica and radioactive minerals on the two exposures originally opened up and have taken out a little mica, as well as a small amount of the uraninite and thucholite material.

Most of the work done in the early days was conducted on an exposure of pegmatite on the upper flank of the mountain forming the northeast side of Lac Pied du Monts, about one mile from the lower end of the lake. These workings lie about 600 feet above the lake, and 100 feet below the summit of the ridge. Here, the exposures suggest a rather flat-lying pegmatitic sill, about 12 feet wide, cutting dark gneiss, and with an apparent northeasterly strike. At the east end, the dyke has been surface-blasted to a depth of 12-15 feet for a distance of about 75 feet along the strike, which is diagonally up the mountain side, and at the lower, or west end, two short tunnels have been driven. The lower of these has been carried in a distance of 50 feet along the strike, on a 25° rise; the upper is 25 feet long, heading diagonally towards the lower one, but not connecting with it. In addition, the present operators have done further work on a shallow pit sunk on the left bank of the small creek flowing out of the lake, about 450 yards from the lake. The creek flows through a narrow gorge, and the

pit has been sunk at the base of the steep rock-wall forming its northeast side, practically at water level. As a result, this working floods rapidly and has to be continuously pumped out when work is proceeding. The pit has been carried to a depth of 30 ft., and from its bottom a drift has been carried 50 ft. to the southeast. All of this work is in pegmatite, but the exposures are insufficient to indicate clearly either the width of the dyke or the strike and dip. There is, however, an apparent width of at least 15 ft., with no walls showing.

The above two sets of workings are at least one mile apart, and, as far as could be learned, no pegmatite outcrops have been located in the intervening section. However, the character of the rock and associated minerals at both sites is so essentially similar that it seems highly probable that we have to do with two outcrops of one and the same dyke.

The pegmatite consists predominantly of pale pink microcline, with lesser amounts of white albite and quartz. The quartz is mostly in modified graphic intergrowth with the feldspar with very little in free, massive form. Biotite is abundant, often in large, thin plates up to 18 inches across. The dyke also carries muscovite, usually of a smoky, brownish colour, in plates up to 6-8 inches in diameter, and the operators reported 1,500 pounds of cut, merchantable muscovite, in various trade sizes, recovered from their mining in 1936. Occasionally, muscovite and biotite occur intimately associated and even intergrown; fine examples of plates of both micas in parallel growth, or showing a crystal of biotite enclosed within one of muscovite, have been found. The biotite is remarkably rich in pleochroic haloes, as recorded by D. E. Kerr-Lawson.² These haloes have been further studied by G. H. Henderson and S. Bateson³ who deduced from them an age of 750 million years. This compares with an age of 1,070 million years calculated by H. V. Ellsworth from an analysis of the uraninite.⁴

Minor accessory minerals of the pegmatite include the following:

Pink garnet, of hessonite colour, occurs in small crystals, usually in localized aggregates associated with small biotite flakes, and enclosed in intergrown white albite and quartz. The garnets are mostly anhedral, shattered, and penetrated by quartz and biotite along the fractures. Associated with them were noted occasional small grains of an undetermined yellowish mineral, having a resinous lustre, and outwardly resembling microlite.

Beryl, of a pale greenish-white colour, occurs in stout prisms up to 2 in. across, and up to 12 in. in length. The crystals usually have a characteris-

² *University of Toronto Studies*, No. 24, 54-70 (1927), and No. 27, 15-27 (1928).

³ *Proc. Roy. Soc., A*, 145, 563-581 (1934).

⁴ See reference 6.

tically rounded, rod-like section, due to the development of a large number of prism faces. Nearly always some of these are obscured by surface alteration, but on some individuals up to 16 faces can be determined. In only a few instances were crystals noted having the typical six-sided outline of beryl, and these individuals were all small—less than $\frac{1}{2}$ in. across. Externally, the crystals are usually coated with a thin film of a dark-green, chlorite-like substance, and not infrequently prismatic striations are filled with small needles of black tourmaline.

Apatite, of olive-green to blue-green shade, occurs in small amount, usually in small, anhedral grains in feldspar.

Zircon is present in fair abundance, in small, lustrous, clove-brown to greenish-black individuals, usually embedded in feldspar or quartz. The crystals are of typical zircon habit, and measure up to $\frac{1}{2}$ in. in length by $\frac{1}{4}$ in. across. No zircon of the cyrtolite variety, so typical of eastern Canadian pegmatites, was observed.

Several small irregular pieces of monazite, the largest measuring $1\frac{1}{2}$ in. by 1 in. by 1 in., were found on washing the specimens selected for weight from a mixed assortment of uraninite, etc., placed at my disposal by the mine management. As several of the uraninite specimens also were found to carry attached broken fragments of monazite, it is probable that all of the pieces of this mineral originally belonged to a single individual that occurred in intimate association with a pockety aggregate of uraninite (see below). The mineral is dark reddish-brown in colour, and contains numerous minute blebs of thucholite and specks of pyrite. The pieces were rough and irregular in form, and showed no crystal faces.

Pyrite and chalcopryrite were observed as small brecciated fragments, and also filling minute veinlets, within a few of the uraninite specimens.

Uraninite

Unfortunately, no details can be given here regarding the manner of occurrence, association, etc., of the uraninite, since only minor traces of the mineral were seen in place. The whole of the material obtained, amounting to some 10 pounds in all, consisted of about 30 individual specimens, picked more or less at random from a box containing a mixed assortment of uraninite and thucholite put at my disposal by the management, and from which the larger and heavier pieces were rather hurriedly selected, with only specific gravity to guide the choice.

The management stated that about 75 pounds, in all, of uraninite were obtained in the four months, June to September, during which the property was worked in 1936. This was taken from both the upper and lower workings, but apparently most of it came from the main pit on the

mountain side, where a single mass, or pocket, was stated to have yielded about 25 pounds. The remainder appears to have been in the form of small, scattered crystals or aggregates disseminated irregularly through the dyke, but probably mainly in a localized zone in the immediate vicinity of the upper tunnel, where the broken rock faces show numerous patches of feldspar of the dark reddish shades typical of colouration by radioactive emanation.

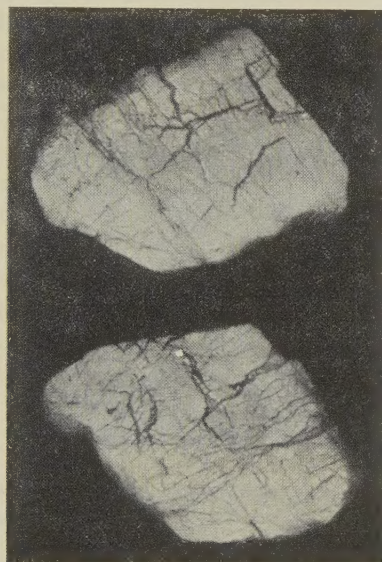


FIG. 1. Radiographs of two halves of a single sliced specimen of uraninite from Lac Pied des Monts, Que. Shows the intensive veining of the material by cracks and minute fissures filled with thucholite. Muench's analysis was made on comparable material. $\frac{2}{3}$ natural size. Exposure 50 hours.

Of the 75 pounds of uraninite reported to have been obtained, however, only about two-thirds, or less, probably would be clean mineral, since the material examined was found to consist largely of masses or cores of uraninite carrying varying amounts of attached pegmatitic material. In nearly all cases, also, the uraninite carries considerable thucholite, in the form both of external crusts and as a network of fine veinlets penetrating right through the cores. In some specimens, small, brecciated nodules and veinlets of pyrite and chalcopyrite occur within the uraninite. Examination of 15 sliced and polished specimens, selected for gravity, showed that very little pure, fresh uraninite could be obtained from them, even the central cores of the largest pieces being extensively seamed by fine veinlets of thucholite.

Owing to the degree of alteration (oxidation) suffered by the uraninite, and to its thucholite content, only the central cores of polished specimen commonly exhibit metallic lustre, this being shown by the small brecciated fragments between the veinlets, and, in general, the mineral has a dull, matt appearance. The colour in the mass is black, but cores less highly veined by thucholite have a steel-blue tone, resembling that of polished Wilberforce uraninite.

Of the specimens obtained, exclusive of those sent to Dr. Lane, of which no record was made, the two largest each measured roughly 3 in. by $2\frac{1}{2}$ in. by 2 in., being practically free of attached gangue. They weighed, respectively, 663 grams and 480 grams. Six pieces were between 2 and

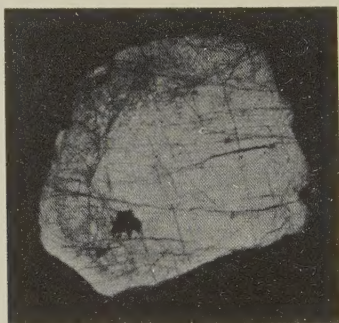


FIG. 2. Radiograph of another specimen of Lac Pied des Monts uraninite, showing rather less intensive veining of core of crystal by thucholite. The small black corroded bleb is biotite. $\frac{2}{3}$ natural size. Exposure 50 hours.

3 in. long and 1 to 2 in. in the other dimensions. The remainder were smaller, down to $\frac{3}{4}$ in. Practically all had suffered some loss by breakage, were of irregular shape, and may be described as roughly nodular, though in a few instances, where the uraninite carried thin plates of biotite on two opposite and approximately parallel, flattened faces, an approach to vein-like form was exhibited. In these latter specimens, also, the thucholite veinlets run predominantly parallel to the long dimension of the specimen, instead of promiscuously, as in the majority of the pieces.⁵ Only on one or two of the smallest specimens could any approach to crystal form be noted.⁶ Two of these are flattened plates, $\frac{3}{4}$ in. across and $\frac{3}{8}$ in.

⁵ Note. The specimens which I gave to Dr. Lane, and which he showed me later, after polishing, also seemed to have vein-like character; in this respect, resembling pitchblende rather than uraninite.

⁶ In this connection, see H. V. Ellsworth's paper *Uraninite from Lac Pied des Monts, Saguenay District, Quebec*: *Am. Mineral.*, 19, 421-425 (1934). Ellsworth there depicts one of the original uraninite specimens secured by Obalski, and describes it of dodecahedral form, with six developed faces, and weighing 375 grams.

thick, and showing rough hexagonal outline vertical to the dominant upper and lower surfaces. All of the apparent 8 faces of these two specimens are rough and irregular, slightly pitted, and carry small amounts of both muscovite flakes and quartz, which indent the uraninite. In addition, one of them is further roughened by a coating of dull, friable thucholite. From its gravity, this last specimen probably has had its original uraninite replaced in large part by thucholite.

The majority of the specimens carry considerable attached mica, either muscovite or biotite, and in some cases both. This mica is often particularly in evidence on two opposite sides of the specimen, suggesting that the uraninite formed within a "book" of mica, forcing the plates apart in the process. This might account for the dominant platy, or vein-like, form of many of the specimens.

Very little of the uraninite has altered to the orange and yellow secondary products so often formed by surface oxidation of this mineral. Only one of the specimens secured showed a minor trace of a yellowish incrustation. Small amounts of a reddish-orange and yellow powder were, however, observed among the friable, weathered material of a small thucholite pocket, or nodule, in the rock-face near the upper tunnel. This proved to be too indefinite for identification, but probably is gummite, or uranophane.

Thucholite

As noted above, practically all of the uraninite examined proved to carry considerable thucholite, both as external crusts of friable, powdery material, and also filling a network of minute veinlets penetrating the entire mass of the uraninite. Many of the uraninite specimens proved, on polishing, to contain only a residual skeletal core, or in some cases, several isolated cores, of uraninite surrounded by thucholite, while the volume represented by the vein thucholite would average probably about 20 per cent of the whole.

So much for the thucholite associated intimately with the uraninite. Of greater interest is that occurring as discrete, and usually nodular, masses in the pegmatite itself. The largest specimen of such nodular thucholite secured measured 3 in. by 2 in., by $1\frac{1}{2}$ in., was of rather rough, irregular shape, and was partly enclosed by a thin concentric shell of muscovite. As with the uraninite, such a mica envelope is characteristic for the thucholite nodules, and the majority of those obtained have it. From the above size, the nodules range down to small bean-like pellets. A number of those secured were of walnut size. The larger ones commonly are elongated, having the shape of a small potato.

All of the larger specimens have suffered considerably from surface,

or near-surface, weathering, and most of them are broken. They consist of very friable material, and break down readily to a granular powder. Curiously, the outer shell seems the most resistant and is usually coherent fresh, and lustrous, while the central core consists of a fine, matt powder. This latter is often grey in colour, and in one specimen is canary-yellow, indicating that the colouration is due to a uranium salt: this yellow powder proved to be feebly fluorescent under the mercury vapour (H-3) lamp.

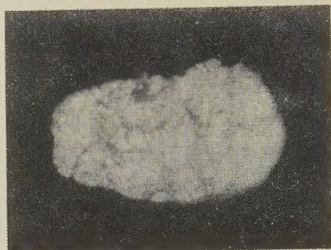


FIG. 3. Radiograph of a small nodule of thucholite from Lac Pied des Monts, Que. The material was very friable and had to be mounted in bakelite for polishing. Natural size. Exposure 96 hours.

The only really fresh thucholite was that of the smallest nodules, of pea to bean size, which were found on the waste dump in fresh, broken masses of pegmatite. In almost every instance, these nodules were enclosed in quartz, only a few being found in a rough, granular aggregate of feldspar and muscovite.

In not a single instance, could any approximation to crystal form be detected on the nodules, such as to suggest that they might be pseudomorphous after uraninite. On the contrary, they all exhibit a concentric, scaly structure, as if the carbonaceous matter had been deposited in a succession of thin layers around a central nucleus. In this respect, the thucholite differs radically from that of the other classic Canadian occurrence of this mineral, the Besner mine, in Henvey township, Parry Sound District, Ontario, where it forms distinct pseudomorphs after uraninite crystals.⁷

Obalski noted the occurrence of thucholite at the Pied des Monts mine, and described it in the report cited above. His analysis gave:

Volatile materials (including combustible gas and water)	40.19%
Fixed carbon	52.59
Ash	7.22
	100.00

The ash was found to contain 35.43 per cent of uranium, and the mineral was determined as radioactive.

⁷ Spence, Hugh S., A remarkable occurrence of thucholite and oil in a pegmatite dyke, Parry Sound District, Ontario: *Am. Mineral.*, **15**, 499-520 (1930).

CLINOBARRANDITE AND THE ISODIMORPHOUS SERIES, VARISCITE-METAVARISCITE

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INTRODUCTION

In 1916, W. T. Schaller (1) suggested the existence of the isodimorphous series, variscite-metavariscite. Until recently no additional data were available to test the validity of this premise, so it seemed desirable to investigate the supposed members of the series by *x*-ray methods.

At an early stage of the investigation it became desirable to study one member of each group in some detail, because *x*-ray measurements had not been made on any of the members of the series. Investigations of phosphosiderite and scorodite were begun simultaneously, the latter in collaboration with Dr. L. J. B. LaCoste. The results for phosphosiderite have recently appeared (2). The work on scorodite led to the tentative selection of $Pcab-V_h^{15}$ as the probable space group, and this agrees with the results of P. Kokkoros (3).

When the intensity measurements failed to yield a plausible structure, the study of scorodite was temporarily discontinued, because specimens of sufficiently good quality to permit more accurate intensity measurements were not available. Furthermore, the crystals were not suitable to the production of Laue photographs which were desired in order to confirm the choice of the space group. Attention was then directed toward the measurement of the several remaining members of the series by powder diffraction methods.

Recently, H. Strunz and K. v. Sztrókay (4) have presented certain data on this mineral series. However, the results obtained in the present study are somewhat more complete and will serve to confirm their results* as well as to supplement them. In addition to giving measurements on metavariscite and variscite, the present work will show the existence of a monoclinic mineral having the composition $(Al, Fe)PO_4 \cdot 2H_2O$, clinobarrandite. The existence of this mineral has not been recognized previously, although its probable existence has been predicted by the writer (5) on the basis of the apparent discrepancies in the optical properties reported for barrandite.

The following specimens were examined in this study:

- I. Scorodite, from Ojuela mine, Mapimi, Durango, Mexico.
- II. Scorodite, from Djebel Debar (Constantine) Algeria. Purchased from Ward's Natural Science Establishment.
- III. Strengite and phosphosiderite, from Pleystein, Wildenau, Germany. U.S.N.M. 95538.
- IV. Variscite and metavariscite, from Lucin, Utah (part of type). U.S.N.M. 87485.

* The choice of the probable space group for phosphosiderite is not confirmed for reasons mentioned below.

- V. Peganite [variscite] from Hot Springs, Arkansas. Kindly furnished by Dr. J. W. Gruner, Minneapolis.
- VI. Barrandite [intimate mixture of clinobarrandite and barrandite] from Manhattan, Nevada, U.S.N.M. 94669.
- VII. Barrandite, from Třenice, Bohemia. Furnished by the Field Museum of Natural History through the kindness of Dr. H. W. Nichols. M4144.
- VIII. Barrandite, from Cerhovic, Bohemia. Purchased from Ward's Natural Science Establishment. No. 1069.
- IX. Phosphate [barrandite with quartz and mixture of dahlite-collophane] from island Gran Roque, Venezuela. Furnished by the Servicio Técnico de Minería y Geología, Caracas, through the kindness of Mr. S. E. Aguerrevere.
- X. Metavariscite and variscite [containing small amount of iron] from Candelaria, Nevada. Kindly furnished by Mr. S. E. Clabaugh.

Unless otherwise indicated the specimens were furnished by the U. S. National Museum through the kindness of Dr. William F. Foshag, to whom the writer is indebted. Some of the powder diffraction patterns used in this study were kindly prepared by Mr. Lynn Gardiner, of the University of Minnesota, Minneapolis.

The completion of this work was made possible by a grant-in-aid from the Society of Sigma Xi and assistance granted by the University Research Institute (Texas), which permitted the purchase of an x-ray tube and cameras. The Department of Physics has kindly cooperated by placing at the writer's disposal the necessary electrical apparatus and laboratory space.

EXPERIMENTAL RESULTS

Powder diffraction diagrams were obtained for all of the specimens accessible through the use of unfiltered iron radiation and precision cameras (M. J. Buerger's model) with $r = 57.3$ mm. Some of the substances measured do not represent pure compounds (end-members) and for this reason the cell edges listed are not the determinations for any particular specimen, but are based on a number of measurements. Presumably, these values are for the pure compounds, or end-members, and are accurate within ± 0.05 Å. Specific gravity measurements from the literature are compared with the calculated densities.

Orthorhombic— P_{cab}		a_0	b_0	c_0	ρ	G
Variscite	$\text{AlPO}_4 \cdot 2\text{H}_2\text{O}$	9.85	9.55	8.50	2.61	2.5
Barrandite	$(\text{Al}, \text{Fe})\text{PO}_4 \cdot 2\text{H}_2\text{O}$					
Strengite	$\text{FePO}_4 \cdot 2\text{H}_2\text{O}$	10.05	9.80	8.65	2.89	2.87
Scorodite	$\text{FeAsO}_4 \cdot 2\text{H}_2\text{O}$	10.30	10.00	8.90	3.32	3.3
Monoclinic ($\beta \rightarrow 90^\circ$)— $P2_1/n$						
Metavariscite	$\text{AlPO}_4 \cdot 2\text{H}_2\text{O}$	5.15	9.45	8.45	2.53	2.54
Clinobarrandite	$(\text{Al}, \text{Fe})\text{PO}_4 \cdot 2\text{H}_2\text{O}$					
Phosphosiderite	$\text{FePO}_4 \cdot 2\text{H}_2\text{O}$	5.30	9.80	8.65	2.74	2.76
[Clinoscorodite]	$\text{FeAsO}_4 \cdot 2\text{H}_2\text{O}$	—	—	—	—	—
? Vilateite	$(\text{Fe}, \text{Mn})\text{PO}_4 \cdot 2\text{H}_2\text{O}$	—	—	—	—	2.75

In the present work the transformation suggested by Strunz and Sztrókay (4) for the variscite group has been adopted, because this permits a more direct comparison of the lattices of the two mineral groups, making the perfect cleavage (010) for both strengite and phosphosiderite. In both cases the imperfect cleavage is (001). This transformation is: Laubmann-Steinmetz to Strunz-Sztrókay 001/100/010.

As already pointed out by Strunz and Sztrókay, however, the space group $P2_1/m$ is not a subgroup of $Pcab$, and the writer had considered this fact prior to the selection of $P2_1/m$ as the probable space group for phosphosiderite.

More recently it has been possible to obtain Weissenberg photographs of metavariscite and it has become quite apparent that the writer (2) and Strunz and Sztrókay (4) overlooked the absence of $h0l$ when $h+l$ is odd on the rotation photographs of phosphosiderite. Thus $P2_1/n-C_{2h}^5$ is the probable space group of metavariscite, clinobarrandite and phosphosiderite, and $P2_1/n$ is a subgroup of $Pcab$.

Measurement of a specimen from Manhattan, Nevada, has proven that this substance is not pure barrandite, but an intimate mixture of barrandite and the dimorphous form, clinobarrandite. In Table 1 the interplanar distances and estimated intensities are compared for clinobarrandite+barrandite VI, strengite and phosphosiderite. The interplanar distances for the monoclinic mineral are intermediate between those of phosphosiderite and metavariscite. Likewise the d values for the orthorhombic substance are intermediate between those of strengite and variscite. This proves that clinobarrandite and barrandite are present, rather than a mixture of phosphosiderite and variscite, or strengite and metavariscite. As neither the monoclinic nor the orthorhombic substance very closely approaches an end-member in composition, E. V. Shannon's analysis (6) will serve to demonstrate the intermediate composition of both substances.

A specimen from Candelaria, Nevada, has been examined and found to be an intimate mixture of variscite and metavariscite, although it contains a small amount of iron. Dr. R. B. Ellestad kindly determined total iron as Fe_2O_3 and obtained 1.32%. The diffraction diagram of this specimen is given in Fig. 1, where the similarity between it and the mixture of clinobarrandite and barrandite is apparent. However, the spacings of the lines are slightly different because of the differences in the cell dimensions.

TABLE 1. COMPARISON OF POWDER DIFFRACTION DIAGRAMS*
 (UNFILTERED Fe RADIATION— $r=57.3$ MM.)

No.	Clinobarrandite + Barrandite			Strengite		Phosphosiderite	
	d	I	Key	d	I	d	I
	—			—		6.48	1
1	5.40	4	B ₅	5.42	5	—	
2	4.87	3	B ₄	4.92	4	—	
	—			—		4.88	1
3	4.65	2	C ₅	—		4.67	5
4	4.50	2		—		—	
5	4.327	8	B ₈ +C ₆	4.338	8	4.327	6
	—			—		4.089	2
6	3.979	1		—		—	
	—			—		3.965	2
	—			3.947	3	—	
	—			3.684	2	—	
7	3.581	1	C ₅	—		3.592	5
8	3.522	1		—		—	
	—			3.378	1	—	
9	3.285	1	C ₂ +B ₂	3.239	2	3.320	2
10	3.087	2	B ₆	3.093	6		
11	3.044	2	C ₃	—		3.052	3
12	2.948	4	B ₄₊₄ {	2.982	4	—	
	—			2.925	4	—	
13	2.802	3		—		2.831	1
14	2.752	8	C ₁₀ +B ₄	2.782	4	2.771	>10
	—			2.675	1	—	
	—			—		2.651	1
	—			2.611	1	—	
15	2.533	5	B ₃ +C ₅	2.514	8	2.557	5
16	2.437	2	B ₄ +C ₁	2.426	4	2.452	1
17	2.332	2	C ₂ +B ₂	2.346	2	2.338	2
	—			2.272	2	—	
	—			—		2.256	2
	—			—		2.221	2
18	2.077	1	B ₅ +C ₃	2.121	5	2.123	3
	—			2.099	2	—	
	—			2.070	3	—	
	—			—		2.064	1
19	2.004	4	C ₅ +B ₄	1.995	4	2.011	5

* The column marked "Key" indicates the source of the lines as clinobarrandite and/or barrandite, the subscripts indicating the relative intensities of comparable lines in the patterns of strengite and phosphosiderite. Beta lines and lines with estimated intensities less than one have been omitted from the table.

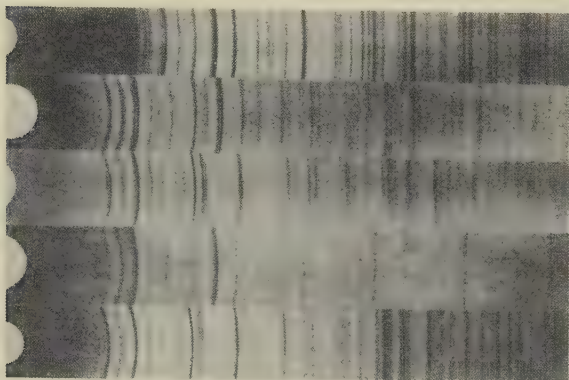


FIG. 1. Comparison of powder diffraction patterns of phosphosiderite, metavariscite + variscite X, barrandite VIII, clinobarrandite + barrandite VI, and strengite (reading from top to bottom).

The following aluminum-iron ratios for specimens of barrandite and clinobarrandite + barrandite are taken from the published analyses.

	Al/Fe
Clinobarrandite + barrandite	
Manhattan, Nevada	0.4
Barrandite	
Cerhovic, Bohemia	0.7
Gran Roque, Venezuela	2.5
Třenice, Bohemia	6.0

Several other minerals were investigated in order to discover any identities which might exist, but these studies have not been completed due to the difficulties in obtaining specimens. Zepharovichite has been found to be identical with wavellite. Callainite produces a pattern distinctly different from either variscite or metavariscite, but its existence as a species is not necessarily confirmed in the present work. S. G. Gordon (9) has suggested the probable identity of globosite and strengite but no opportunity to check this was afforded. The description of eggonite suggests its probable identity with either variscite or metavariscite. A specimen was not available for examination in this study, however.

DISCUSSION

Barrandite is now known from seven localities, namely, Třenice (7) and Cerhovic (8) in Bohemia; Manhattan, Nevada (6); Moore's Mill, Pennsylvania (9); the island Gran Roque, Venezuela (5); the island Con-

nétable, French Guiana (10) and Ninghanboun, S. W. Australia (11).^{*} This suggests that barrandite is not as rare in its occurrence as previously supposed. At Gran Roque it is the chief constituent of the phosphate deposit, and it may be the iron- and aluminum-bearing constituent of other rock phosphates.

Strunz and Sztrókay introduced the term "clinoscorodite" to apply to the dimorphous form of scorodite. The evidence for the existence of this dimorphous form is the variation in the optical properties observed by E. S. Larsen (12). Although clinoscorodite has been included in the tabulation, it is noteworthy that the goniometric measurements and refractive index determinations by T. Ito and T. Shiga (13) do not support the supposition that the material from Kiura mine, Bungo, Japan, is clinoscorodite, unless both scorodite and clinoscorodite occur at this locality. The association is probable, however, in view of the frequent association of other dimorphous pairs.

The relation of vilateite to this series is not quite clear and a specimen could not be obtained for investigation. If Himmelbauer's form (301) is taken as (101) the following comparison results.

Phosphosiderite	Vilateite
$a:b:c=0.545:1:0.897$	$a:b:c=0.565:1:0.889$
$\beta = 89^{\circ}24'$	$\beta = 89^{\circ}27'$
$G=2.76$	$G=2.75$
$n_{\beta}=1.725$	$n_{\mu}=1.74^a$
$r>v$ very strong negative	$r>v$ strong negative

It is to be remembered that the isodimorphism of the variscite—metavariscite series depends upon one assumption which seems to be well founded: the degree of hydration is the same for the members of both groups. The specimens studied in the present work were not suitable for accurate determinations of the water of hydration.

SUMMARY

The name clinobarrandite is proposed for a new mineral which is monoclinic and has the same composition as barrandite, $(\text{Al}, \text{Fe})\text{PO}_4 \cdot 2\text{H}_2\text{O}$. The probable space group of metavariscite, clinobarrandite and phosphosiderite is $P2_1/n$. Lattice dimensions are given for the members of both groups of the isodimorphous series.

^{*} This material, intermediate in composition between variscite and strengite, was described as "variscite (redondite)." The term "redondite" carries no mineralogical connotation whatever. This so-called mineral is probably identical with barrandite which has priority. If it is not identical, the term should not be applied until its properties have been established. A chemical analysis made on heterogeneous material is not a sufficient basis for the introduction of a new mineral name.

^a $n_{\mu} = (n_{\alpha} + n_{\gamma})/2$, or mean index.

Metavariscite is reported from Candelaria, Nevada thus recording a second locality, for this species.

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^b Schaller's lucinite = variscite and variscite = metavariscite. See: Larsen, E. S., and Schaller, W. T.: *Am. Mineral.*, **10**, 23-28 (1925).

STUDIES OF MINERAL SULPHO-SALTS: IV—GALENO-BISMUTITE AND "LILLIANITE"

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ABSTRACT

Single crystal x -ray measurements on galenobismutite from Nordmark Mines, Sweden (type specimen) give the following structural data: orthorhombic; space group, $D_{2h}^{16}-Pnam$ or C_{2v}^9-Pna2 . Cell edges, a_0 11.72 ± 0.03 , b_0 14.52 ± 0.03 , c_0 4.07 ± 0.02 Å. Unit cell contains $Pb_4Bi_8S_{16} = 4[PbS \cdot Bi_2S_3]$. Specific gravity 7.04 (highest of three measurements), 7.18 (calculated). Polished sections, white, strongly anisotropic; etch-reactions: HNO_3 , at once effervesces violently, etches deeply and leaves yellow deposit; HCl , gives a slight brown stain; KCN , $FeCl_3$, KOH , $HgCl_2$, negative.

Galenobismutite from Cariboo Gold Quartz Mine, British Columbia, and 'lillianite' from Mt. Farrell, Tasmania, gave powder patterns identical with that of the type material. 'Lillianite' from Gladhammar is shown by polished sections and x -ray photographs to be a mixture of galena and galenobismutite. Flink's crystals of 'lillianite' evidently represent the only known occurrences of distinct crystals of galenobismutite. These observations confirm the individuality of Sjögren's galenobismutite and show that 'lillianite' has no standing as a mineral species.

Galenobismutite was first described from the Kogrufvan, Nordmark, Sweden, by Sjögren (1878) who derived the composition $PbS \cdot Bi_2S_3$. There appears to be no subsequent description of a homogeneous mineral with this composition. Weibull (1885) described a seleniferous material from Falun, Sweden, as *seleniferous galenobismutite*, later named *weibullite* by Flink (1910). Dana (1892) accepted this 'seleniferous galenobismutite' along with the *alaskaite* of Koenig (1881) as varieties of galenobismutite. Murdoch (1916, p. 130), Walker and Thomson (1921, p. 12) and Schneiderhöhn and Ramdohr (1931, p. 396) all worked with the seleniferous material, which had become known as galenobismutite, and found it to be a mixture; and thus the individuality of galenobismutite has been widely questioned. Specimens of this mixed mineral were examined and found to contain two minerals, neither of which is galenobismutite; these will be described on another occasion.

Lillianite, a new mineral with the composition $3PbS \cdot Bi_2S_3$, was described from the Lillian Mine, Leadville, Colorado by Keller and Keller (1885) and Keller (1889). Material from the type locality has since been shown to be a mixture, by Emmons, Irving and Loughlin (1927, p. 170). The name lillianite was later applied by Flink (1910) to a mineral from Gladhammar, Sweden, previously analyzed by Lindström (1889). Analyses of this material by Mauzelius, in Flink (1910), agreed well with the early analysis by Lindström (1889). The same material was again examined by Walker and Thomson (1921) and analyzed by Todd, who confirmed the previously reported composition. Walker and Thomson

concluded that this material is homogeneous; our specimens, however, prove to be a mixture of galena and galenobismutite, and therefore a description of this so-called 'lillianite' is appropriate in the present connection.

Professor G. Aminoff in Stockholm kindly supplied a fragment from the specimen of galenobismutite originally described and analyzed by Sjögren (1878), thus making it possible to re-examine this mineral and determine its specific properties. The specimens of 'lillianite' were made available by Professor A. L. Parsons. The material from British Columbia was received from Professor H. V. Warren, who will give further descriptive details elsewhere. Professor M. A. Peacock has given me some useful suggestions and has helped in the preparation of this paper.

MATERIALS

The following materials proved to be galenobismutite or to contain this mineral.

1. Galenobismutite, Kogrufvan, Nordmark Mines, Sweden (type material). "Naturhistoriska Riksmuseum, Stockholm, yellow 3987"; crystalline, indistinctly columnar aggregate. This is the material analyzed and named by Sjögren (1878).

2. 'Lillianite' (Royal Ontario Museum of Mineralogy, M/14076), Mt. Farrell, Tasmania; crystalline, indistinctly columnar aggregate with calcareous gangue.

3. 'Lillianite' (R.O.M.O.M., M/11826 and polished section A.2.3.2.), Gladhammar, Sweden; fibrous aggregate intimately intergrown with galena. Analyzed by Todd, in Walker and Thomson (1921).

4. Galenobismutite (R.O.M.O.M., M/19716), Cariboo Gold Quartz Mine, Barkerville, Cariboo District, British Columbia; Crystalline, indistinctly columnar aggregate with cosalite and gold in quartz.

The *x*-ray measurements were made on the type material; the identity of the remaining specimens was established by means of *x*-ray powder photographs.

PHYSICAL PROPERTIES

Galenobismutite forms indistinctly columnar aggregates showing poor longitudinal cleavage. It is tin-white in colour with metallic lustre. Specific gravity measurements on three different fragments from material 1 gave 7.04, 7.01, and 6.96 as compared with 6.88 noted by Sjögren. The published specific gravity of 'lillianite' from Gladhammar ranges from 7.00 to 7.14, due to the presence of more or less galena with specific gravity 7.5.

In polished sections galenobismutite is whiter than galena and strongly anisotropic, the polarization colours being yellow to dark brown. Standard etch-reactions: HNO_3 , immediately gives violent effervescence, leaving a deeply etched surface and a yellow deposit; HCl gives a slight

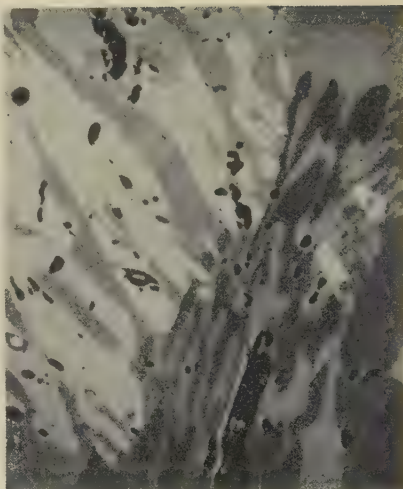
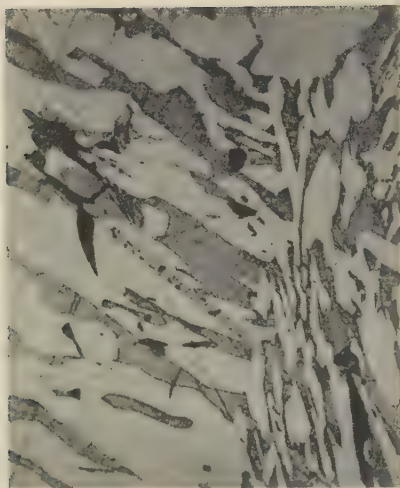


FIG. 1. Galenobismutite ('lillianite'), Gladhammar, Sweden (material 3); galenobismutite (light grey, unetched) intergrown with galena (darker grey, etched with FeCl_3). Vertical illumination; $\times 60$.

FIG. 2. The same; galenobismutite (light grey and dark grey) intergrown with galena (intermediate shade of grey). Unetched; crossed nicols; $\times 60$.



FIG. 3. Galenobismutite ('lillianite'), Gladhammar, Sweden (material 3); fine-grained intergrowth of galenobismutite (light grey, unetched) and galena (darker grey, etched with FeCl_3). Vertical illumination; $\times 90$. •

brown stain; KCN, negative; FeCl_3 , negative; KOH, negative; HgCl_2 , negative. Hardness B, estimated by the steel needle. Published etch-reactions for galenobismutite (Short, 1934) are not reliable since they were made on the so-called 'seleniferous galenobismutite.'

Three polished sections of 'lillianite' from Gladhammar are shown in Figs. 1, 2, 3. Figure 1 shows galenobismutite (unetched) intergrown with galena (etched by FeCl_3). Figure 2, taken under crossed nicols, shows regular intergrowths of the strongly anisotropic galenobismutite with isotropic galena. Figure 3 shows elongated inclusions of galena oriented with the direction of elongation of the galenobismutite.

STRUCTURAL CRYSTALLOGRAPHY

A cleavage fragment about 0.4 mm. long by 0.08 to 0.1 mm. thick was obtained from material 1. The long edge of this fragment proved to be the shortest lattice period and therefore the properly chosen vertical axis. The cleavage or cleavages are therefore in the zone [001], but the indices could not be determined.

A rotation photograph (Fig. 4) about the axis of elongation of the fragment showed the zero, first and second layer lines, giving the lattice period:

$$c_0 = 4.07 \pm 0.02 \text{ \AA}$$

Weissenberg photographs (Figs. 5, 6) of the zero and first layer lines showed orthorhombic symmetry, with 14 orders of $h00$ and 18 orders of $0k0$ including the orders extinguished by the space group symmetry and the structure. Owing to the general weakness of the diffractions $h00$, three strong diffractions $3h \cdot 2h \cdot 0$ were taken into account in deriving the remaining lattice periods:

$$a_0 = 11.72 \pm 0.03 \text{ \AA}$$

$$b_0 = 14.52 \pm 0.03 \text{ \AA}$$

The systematically missing spectra conform to the conditions:

$$h0l \text{ present only with } h \text{ even}$$

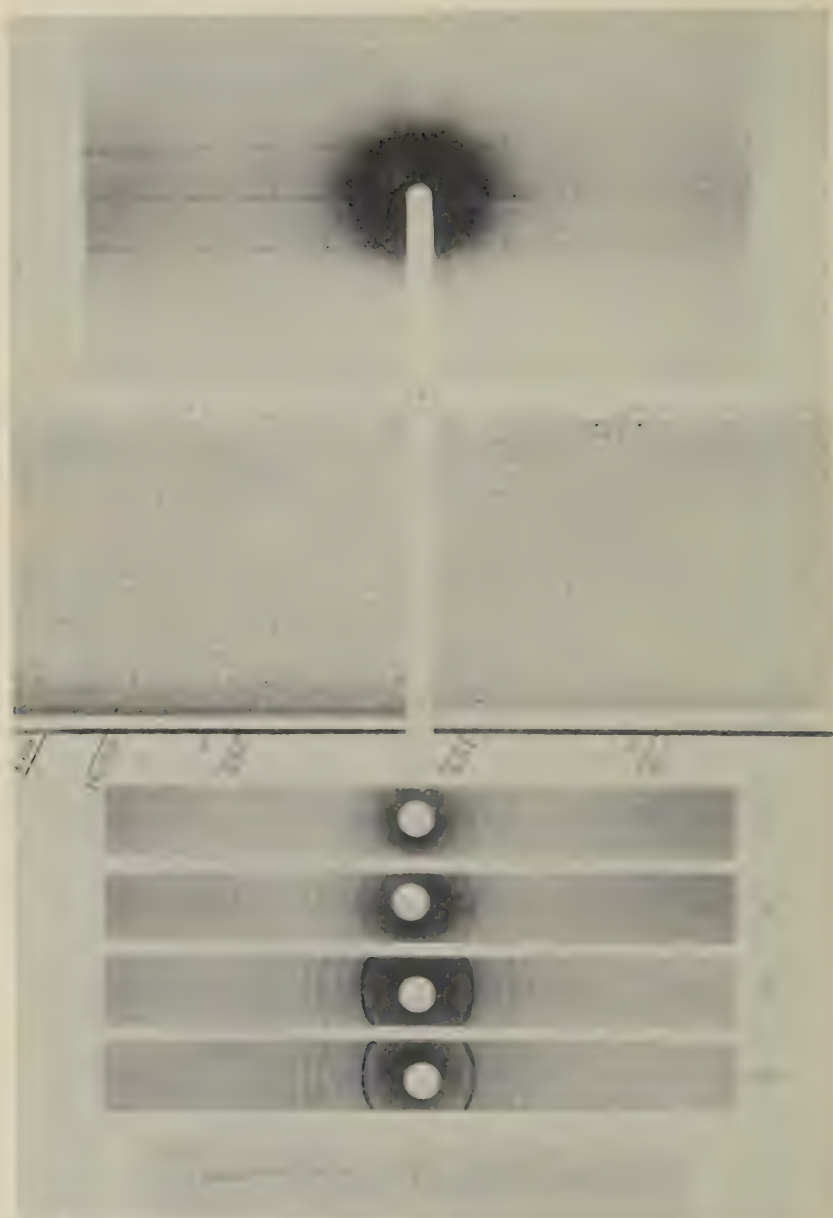
$$0kl \text{ present only with } k+l \text{ even}$$

These conditions are characteristic for the space groups:

$$D_{2h}^{16} - Pnam \text{ or } C_{2v}^0 - Pna2$$

The chosen orientation is the normal orthorhombic setting in which c_0 is the shortest and b_0 the longest edge of the rectangular lattice cell.

Flink (1910, p. 13) described and figured distinct orthorhombic crystals from the material called 'lillianite' from Gladhammar, which we have



(See opposite page for description of figures.)

shown to consist of a mixture of galena and galenobismutite. For these crystals Flink obtained the elements:

$$a:b:c=0.8002:1:0.5433$$

and noted the forms (100), (010), (110), (210), (011).

By halving Flink's *c*-axis the axial ratio:

$$a:b:c/2=0.8002:1:0.2717$$

agrees very fairly with the structural ratio for galenobismutite:

$$a_0:b_0:c_0=0.807:1:0.280$$

In the new setting Flink's forms become (100), (010), (110), (210), (021). There can be no question, therefore, that Flink's crystals of 'lillianite' were, in fact, galenobismutite and that they actually represent the only crystals of this mineral that have ever been measured.

POWDER PHOTOGRAPHS

Identical powder photographs (Figs. 7, 8, 9, 10) were obtained from materials 1, 2, 3 and 4. In the case of 'lillianite' from Gladhammer (material 3), the sample was obtained from the polished section by scraping the unetched portion of the intergrowth with galena.

Table 1 gives the *x*-ray powder spectrum of galenobismutite which has been indexed with reference to the cell elements already determined. A number of lines, with θ -values greater than 35° , although clearly visible on the films, were too indistinct to be measured accurately. The photographs and tabulated data will be sufficient for future identification of the species.

FIGS. 4-10. X-ray photographs of galenobismutite; copper radiation; radius of cameras, $360/4\pi$ mm.

FIG. 4. Rotation photograph about $c[001]$; 1.5 KWH (unfiltered).

FIG. 5. Weissenberg photograph of the zero layer line $/hk0/$, with some diffractions due to a sub-parallel individual; 23.0 KWH (unfiltered).

FIG. 6. Weissenberg photograph of the first layer line $/hk1/$; 21.5 KWH (unfiltered).

FIG. 7. Sweden (galenobismutite, material 1); powder photograph; 10.8 KWH (nickel filter).

FIG. 8. Tasmania ('lillianite,' material 2); powder photograph; 5.9 KWH (nickel filter).

FIG. 9. Sweden ('lillianite,' material 3); powder photograph; 4.6 KWH (nickel filter).

FIG. 10. British Columbia (galenobismutite, material 4); powder photograph; 3.4 KWH (nickel filter).

TABLE 1. GALENOBISMUTITE: X-RAY POWDER SPECTRUM

s_{Cu}	I_P	$d_{meas.}$	hkl	$d_{calc.}$	I_w
12.3	w	3.67	040	3.84	vvs
13.0	vvs	3.47	{140	3.47	vs
			320	3.44	vvs
13.3	vw	3.39	{121	3.40	vvs
			201	3.34	vs
13.9	vw	3.25	211	3.26	m
14.9	s	3.03	{330	3.04	m
			131	3.02	vs
16.2	w	2.79	311	2.77	s
17.0	vw	2.66	{420	2.72	s
			340	2.66	m
18.3	s	2.47	241	2.46	s
19.0	m	2.38	401	2.38	vvs
20.1	vw	2.26	260	2.24	vs
20.7	vw	2.19	251	2.19	s
22.1	s	2.06	360	2.06	vs
22.6	vw	2.02	511	2.01	vs
			{441	1.989	s
23.1	s	1.975	112	1.986	—
			261	1.960	s
			521	1.958	vs
24.0	vw	1.905	212	1.906	—
24.3	m	1.882	{531	1.874	vs
			460	1.866	vs
25.9	s	1.772	{232	1.787	—
			042	1.775	—
26.6	vw	1.729	640	1.720	vs
			242	1.699	—
27.1	vw	1.699	{461	1.696	w
			470	1.693	m
			740	1.520	s
30.8	vw	1.510	{442	1.518	—
			721	1.514	s
			651	1.506	m
			291	1.453	m
32.2	m	1.451	{571	1.452	m
			0.10.0	1.452	s
33.1	m	1.415	2.10.0	1.410	s
34.1	m	1.378	{801	1.378	s
			811	1.372	vs

s_{Cu} —Semi-diameter of powder ring as measured on the film (mm.). I_P —Intensity estimated visually. $d_{meas.}$ —Corrected planar spacing (Å), using $\theta = s - 0.2$ mm. hkl —Indices of the powder ring. $d_{calc.}$ —Planar spacing (Å) calculated from the cell dimensions. I_w —Intensity of the corresponding Weissenberg spot, if in the range of the photographs taken.

COMPOSITION AND CELL CONTENT

The cell dimensions of galenobismutite (material 1) combined with the highest measured specific gravity $G = 7.04$, give the molecular weight of the cell content, $M_0 = 2957$. Applying this number to the better of the two original analyses of the type material we obtain the atomic content shown in Table 2.

TABLE 2. GALENOBISMUTITE: ATOMIC CONTENT OF UNIT CELL

	1	2	3	4	5
Pb	27.65	0.2773	0.001338	3.96	4
Bi	54.69	0.5486	0.002625	7.76	8
S	17.35	0.1714	0.005429	16.05	16
	99.69	1.0000			

1. Analysis by Sjögren (1878). 2. Analysis reduced to the sum of unity. 3. Atomic proportions. 4. Numbers of atoms in unit cell, obtained by multiplying the values under 3 by the molecular weight 2957. 5. Ideal cell content of galenobismutite.

As shown in column 4, the cell content of galenobismutite closely approaches $\text{Pb}_4\text{Bi}_3\text{S}_{16} = 4[\text{PbS} \cdot \text{Bi}_2\text{S}_3]$ thus confirming the empirical formula found by Sjögren. For a cell containing $\text{Pb}_4\text{Bi}_3\text{S}_{16}$ the calculated gravity is 7.18, in fair agreement with the measured value of 7.04.

The analyses of 'lillianite' from Gladhammar are useless to confirm the composition of galenobismutite, since they represent mixtures with galena. The analyses show that the intergrowth consists of about 37 per cent of galena and 63 per cent of galenobismutite by weight.

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A DEVICE FOR MEASURING THE EXTINCTION ANGLE

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The present tendency to obtain more accurate data in petrographic studies has led to a number of methods that give quantitative results.

The apparatus described here enables one to determine extinction angles of crystals in thin sections more accurately than by other methods formerly applied. Moreover, it has the advantage of being free from personal error.

It is hoped that by using the apparatus described below more quantitative petrographic work will be done.

THE APPARATUS

The first step in the construction of the extinction angle apparatus was the use of a cesium photoelectric cell and a galvanometer. The original apparatus, consisting of a photoelectric cell and galvanometer did not show sufficient sensitivity.

Our recent apparatus has a single stage amplifier to obtain good sensitivity, so that a small crystal, less than 1 mm., is easily measured, if there is no other crystal in the microscope field.

Sensitivities are recorded in three stages—high, medium, and low. At the same time a single stage amplifier eliminates the inconvenience of using a galvanometer, lamp and scale.

The entire apparatus is divided into three parts: a light receiving chamber including a photoelectric cell, an amplifying tube with high resistance, battery box and micro-ammeter.

The light receiving chamber, which is easily attached directly to the microscope tube, is connected to the battery box with a flexible cable, as is also the micro-ammeter.

Details for the electrical connections are shown in the following diagram. They are connected so as to eliminate the dark current of a vacuum tube.

DIRECTIONS FOR USE

(1) A crystal to be measured must be placed at the center of the microscope field, and then observed whether the crystal is large enough to cover the microscope field.

If the crystal is not large enough, a more powerful objective lens must be employed. The direction of a cleavage trace or the crystal edge must be determined on the microscope stage.

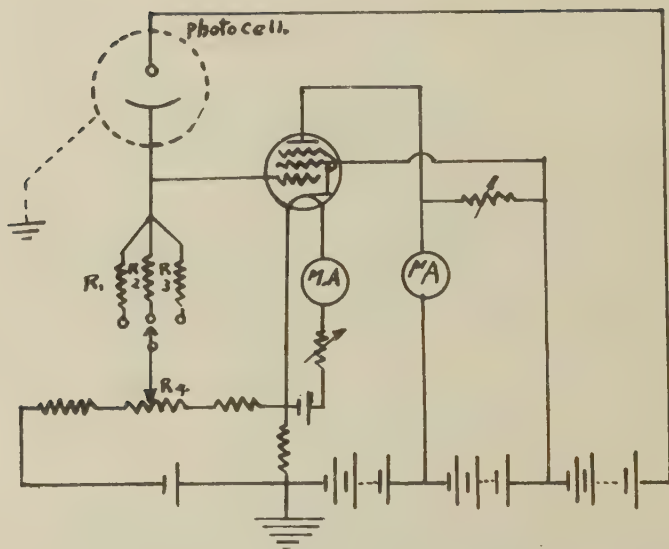


FIG. 1. R_1 , R_2 , R_3 are high resistances $1000\text{M}\Omega$, $500\text{M}\Omega$, and $100\text{M}\Omega$ each. R_4 acts as zero adjustable resistance.

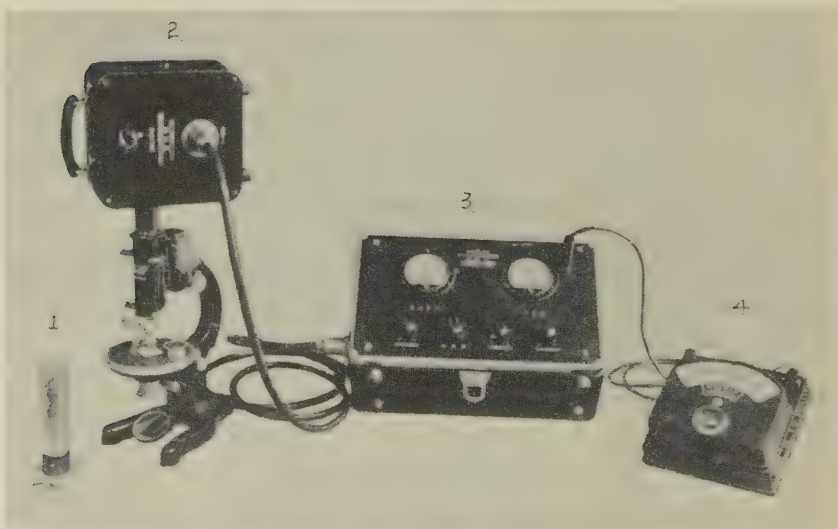


FIG. 2. Photograph shows the apparatus in position for measuring the extinction angle.
 (1) Na-lamp as a light source.
 (2) Microscope and light receiving chamber.
 (3) Battery box to which milli-ammeter and rheostats are connected.
 (4) Micro-ammeter.

(2) Attach the light receiving chamber, in place of the eye-piece. Of course suitable sensitivities are selected in each case.

(3) Turn the stage, and determine the extinction angle between the minimum amplitude of the micro-ammeter and the direction of the

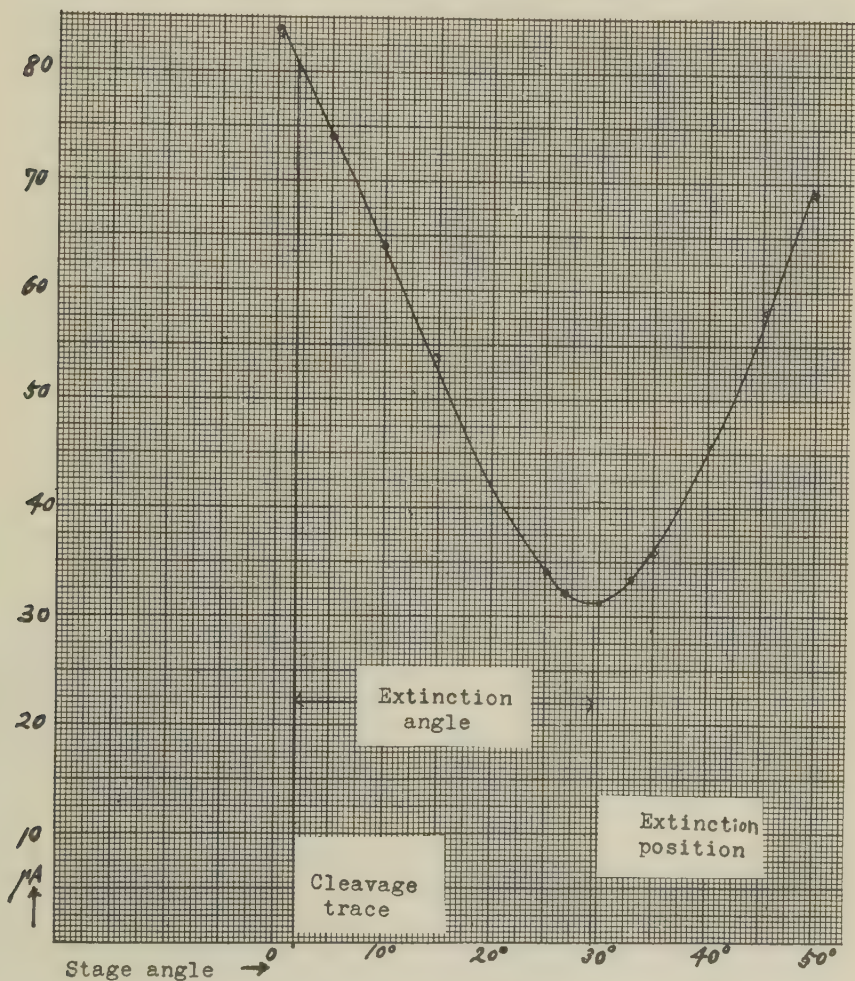


FIG. 3

cleavage trace, or draw a diagram of the stage angle and micro-ammeter amplitude.

Figure 3 shows the result of extinction angle measurements of diopside with a Na-lamp.

The extinction angle can be measured within an error of 30 minutes. This apparatus is also used in saccharimetry.

CLASSIFICATION OF MINERALS OF THE TYPE $A_3(XO_4)_2 \cdot nH_2O^*$

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INTRODUCTION

The purpose of this paper is to present a logical classification of the minerals of the chemical type $A_3(XO_4)_2 \cdot nH_2O$ based upon an investigation of the chemical and physical properties of the various minerals comprising it, together with a determination of the lattice constants.

It has been necessary to make a rather complete study of many minerals which, heretofore, have been imperfectly described. The crystallography, the structural cell with its constants and contents, the specific gravity (measured and calculated), the hardness, the cleavage, and the optical properties have been determined. These properties indicate the position of the minerals in the classification and, likewise, their relations to each other. In some few instances, adequate material was not available, and therefore a thorough study could not be made.

In the discussion of the classification, the extent to which minerals of like chemistry and crystallography are also related in their other properties will be pointed out, since one of the purposes of this study was to discover the extent of such relations. Data derived from the literature have been checked in the course of this work. New data, which have been secured during this research, will be indicated as such. If the data concerning any one mineral are complete or nearly so, only points of question or of interest for the classification are discussed; the remainder of the data is summarized in the tables.

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PREVIOUS CLASSIFICATIONS

Previous classifications by Dana (1892 and earlier), Hintze (1898–1938), and Doelter (1911–1931) of the minerals considered here, which were based on relatively insufficient data, were necessarily only approximations to an adequate systematic treatment. Aside from some members of the vivianite group, practically all of the mineral descriptions up to the time of publication of the above classifications were faulty in one way or another. With the data since published, plus new data obtained during the course of this investigation, it has been possible to develop a satisfactory classification and an understanding of the relations between the various minerals. Strunz and Schroeter (1939) have recently proposed a complete classification of the phosphates and arsenates, but those authors likewise, were without sufficient data concerning the minerals of this type. Aside from the vivianite group, but few of the minerals described and discussed here are included in their classification.

PROPOSED CLASSIFICATION OF THE CHEMICAL TYPE $A_3(XO_4)_2 \cdot nH_2O$ $A_3(XO_4)_2 \cdot 2H_2O$ family

Triclinic group

Collinsite	$Ca_2(Mg, Fe)$	$(PO_4)_2 \cdot 2H_2O$
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Fairfieldite	$Ca_2(Mn, Fe)$	$(PO_4)_2 \cdot 2H_2O$
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Monoclinic group

Roselite	$Ca_2(Co, Mg)$	$(AsO_4)_2 \cdot 2H_2O$
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Brandtite	Ca_2Mn	$(AsO_4)_2 \cdot 2H_2O$
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 $A_3(XO_4)_2 \cdot 3H_2O$ family

Orthorhombic group

Reddingite	$(Mn_{3/4}, Fe_{1/4})_3$	$(PC_4)_2 \cdot 3H_2O$
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 $A_3(XO_4)_2 \cdot 4H_2O$ family

Triclinic group

Parahopeite	Zn_3	$(PO_4)_2 \cdot 4H_2O$
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Anapaite	Ca_2Fe	$(PO_4)_2 \cdot 4H_2O$
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Messelite	$Ca_2(Fe, Mg)$	$(PO_4)_2 \cdot 4H_2O$
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Stewartite	Mn_3	$(PO_4)_2 \cdot 4H_2O ?$
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Monoclinic group

Phosphophyllite	$Zn_2(Fe, Mn)$	$(PO_4)_2 \cdot 4H_2O$
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Orthorhombic group

Hopeite	Zn_3	$(PO_4)_2 \cdot 4H_2O$
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 $A_3(XO_4)_2 \cdot 5H_2O$ family ?

Trichalcite	Cu_3	$(AsO_4)_2 \cdot 5H_2O ?$
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 $A_3(XO_4)_2 \cdot 8H_2O$ family

Triclinic group

Symplesite	Fe_3	$(AsO_4)_2 \cdot 8H_2O$
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Monoclinic group

Vivianite	Fe_3	$(PO_4)_2 \cdot 8H_2O$
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Annabergite	Ni_3	$(AsO_4)_2 \cdot 8H_2O$
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Erythrite	Co_3	$(AsO_4)_2 \cdot 8H_2O$
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Köttigite	Zn ₃	(AsO ₄) ₂ 8H ₂ O
Bobierite	Mg ₃	(PO ₄) ₂ 8H ₂ O
Hoernesite	Mg ₃	(AsO ₄) ₂ 8H ₂ O
A ₃ (XO ₄) ₂ · nH ₂ O family		
Amorphous group		
Collophanite	Ca ₃	(PO ₄) ₂ nH ₂ O

BASIS OF DIVISION INTO FAMILIES

The major divisions in a chemical type are families, which are grouped together according to the chemical similarity of the members. It is to be expected that the members of any one family will show certain additional similarities in their crystallography and physical properties. Thus, it is essential to choose one variable as the basis of division into families which will result in a grouping which satisfies this expectation.

There are but three variables in the chemistry of the minerals of this type: the cations (Mg, Ca, Mn, Fe, Co, Ni, Cu, and Zn), the radicals (PO₄ and AsO₄), and the number of water molecules in the simplest formula. Necessarily, then, any division into families must be based upon one of these. Previous experience and the facts revealed by this study demonstrate that the identity of the cation or cations, though of great importance in the determination of the structure, is of little service for classification, for there is no definite similarity between various minerals containing the same cation, while often minerals in which the cations differ show similar physical and crystallographic properties. Likewise, experience has shown that the radicals in the various minerals tend to affect the unit cell volumes and the crystallographic properties, but certain minerals containing the same radicals do not show sufficiently similar properties to group them together. We must, therefore, examine the role of water in determining the properties and relations of the minerals of this chemical type.

THE ROLE OF WATER

Those minerals containing the same number of water molecules show, as will be demonstrated here, certain definite similarities, which are only slightly modified by the cations and the radicals. It would seem, then, that the minerals might be separated into families on the basis of the number of water molecules present.

Of the two kinds of water combinations theoretically possible in these minerals, zeolitic or water of crystallization, the latter is indicated for the following reasons. First, although the water can be driven off at relatively low temperatures (Spencer, 1908, has given rate of dehydration curves for hopeite and parahopeite demonstrating this), the crystal structure becomes immediately unstable, leading to the disintegration of the crys-

tals. Second, there is direct correlation between the cell volume, the physical properties, and the number of water molecules present. Table 1 shows the interrelation of water content, cell volume, specific gravity, and hardness. Allowance must be made for the effect of the cations and radicals upon these properties, especially the volume and density. For all cases the cell volumes have been divided by the number of molecules in the unit cell to make them directly comparable.

TABLE 1. RELATION OF PROPERTIES TO WATER CONTENT

Mineral	Water Content per Unit Cell	Molecules in Unit Cell	Cell Volume per Molecule	G.	Hardness
Collinsite	2H ₂ O	1	184.5	2.99	3.5
Fairfieldite	2H ₂ O	1	197.2	3.08	3.5
Roselite	4H ₂ O	2	197.2	3.695	3.5
Brandtite	4H ₂ O	2	201.5	3.67	3.5
<i>Average</i>			195.1		
Reddingite	12H ₂ O	4	208.3	3.22	3.5
Parahopeite	4H ₂ O	1	228.8	3.31	3.75
Anapaite	4H ₂ O	1	234.9	2.81	3.5
Phosphophyllite	8H ₂ O	2	235.5	3.19	3.5
Hopeite	16H ₂ O	4	245.1	3.04	2.5-3
<i>Average</i>			236.1		
Annabergite	16H ₂ O	2	304.9	3.24	2
Vivianite	16H ₂ O	2	305.2	2.71	1.5-2
Köttigite	16H ₂ O	2	307.0	3.33	2.5-3
Bobierite	32H ₂ O	4	309.5	2.17	—
Erythrite	16H ₂ O	2	310.2	3.18	1.5-2.5
Symplesite	8H ₂ O	1	321.8	3.01	2.5
<i>Average</i>			309.8		

The minerals have been arranged in Table 1 according to their increasing volumes. In spite of the modifying influence of the cations and radicals, it will be seen that there is a periodic increase of approximately 19 cubic Ångströms for each molecule of water, so that the 4H₂O family averages approximately 41 cubic Ångströms more in volume than the 2H₂O family, and the 8H₂O family approximately 114 cubic Ångströms more than the 2H₂O family.

The cell volume is an inverse function of the specific gravity. Further-

more, as has been shown by Stillwell, Evans, and others, the hardness of minerals is intimately related to water content. In this case, this means that hardness must also be related to cell volume, and this is demonstrated in Table 1.

F. W. Clarke (1874) studied the role of water by a method very similar to the volumetric method given above. He tried to determine whether the molecular volume (molecular weight divided by density) of water of crystallization is a constant quantity, or whether it is different for different salts. He worked on the assumption that the volume of the anhydrous salt remained constant when the salt was hydrated and that the change in molecular volume was due only to the addition of water. If this were true, he expected to find a constant value for the volume of one water molecule in the same type of compound. There was, as far as Clarke knew, no *a priori* reason why this should be so, but calculations of many quite different species demonstrated that water of crystallization has a fairly constant molecular volume, the average of all of his results being 13.76.

Clarke concludes, "When water unites with an anhydrous salt to become water of crystallization, that water undergoes the entire condensation which ensues, the volume of the salt, itself, remaining unaltered." In the "true hydrates," however, Clarke found no uniformity for the molecular volume of water in combination and concluded that both the salt and the water underwent condensation during combination.

The formula used to obtain the molecular volume, $M/d = \text{molecular volume}$, is the same as that for the unit cell volume, $A_0 M_0 / d_0 = V_0$, save for the omission of the Avogadro constant, A_0 . Thus, the volume in cubic Ångströms of one molecule may be obtained from the molecular volume simply by multiplying by the Avogadro constant, 1.6498. The converse is likewise true.

It was noted earlier that the average increase in volume per water molecule was approximately 19 cubic Ångströms. This, converted into the equivalent molecular volume by the method just outlined, would be equal to 11.52, which is somewhat lower than the 13.76 obtained by Clarke. It must be remembered, however, that no allowance has been made in the figure of 19 cubic Ångströms for the effect of variation in cations and anions; so the significance of the difference between the two figures may not be great.

A better check might be found in existing *x*-ray work on compounds whose only difference lies in the number of water molecules present. An examination of the literature discloses data on but few of the many possible examples. These are listed below in Table 2. It must be pointed out in connection with this table that the molecular volume of water in

TABLE 2. MOLECULAR VOLUME OF WATER CALCULATED FROM CELL VOLUMES

Compound	Cell Vol- ume	Molecular Content of Unit Cell	Cell Volume Molecular Content	Vol. 1H ₂ O	Vol. 1H ₂ O	Reference
					A ₀	
LiCl	135.4	4	33.85	—	—	Ott—1923
LiCl · H ₂ O	56.1	1	56.1	22.5	13.48	Ott—1923
NaBr	212.0	4	53.0	—	—	Ott—1924
NaBr · 2H ₂ O	405.5	4	101.4	24.2	14.67	Wooster—1932
NaI	269.8	4	67.46	—	—	Wyckoff—1931
NaI · 2H ₂ O	217.6	2	108.77	20.65	12.52	Wooster—1932
LiI	216	4	54.0	—	—	Wyckoff—1931
LiI · 3H ₂ O	262	2	131.0	25.67	15.56	West—1934
<i>Average</i>					14.05	
CaCrO ₄	335	4	84.0	—	—	Clouse—1932
CaCrO ₄ · H ₂ O	823.8	8	103.0	19	11.5	Clouse—1932
CaCrO ₄ · 2H ₂ O	1022.0	8	128.0	22	13.33	Clouse—1932
NiSO ₄ · 6H ₂ O	845	4	221	—	—	Beevers } Lipson } —1932
NiSO ₄ · 7H ₂ O	961.5	4	240.4	19.4	11.75	Beevers } Schwartz } —1931
CaSO ₄	318	4	79.5	—	—	Rinne—1925
CaSO ₄ · 2H ₂ O	984	8	123.0	21.75	13.18	Onorato—1929
<i>Average</i>					12.44	

the strongly polar halides is appreciably higher than in the chromates and sulphates, these last being more nearly comparable with the compounds dealt with here. The average value obtained from the chromates and sulphates alone is 12.44, which is very close to the value of 11.52 obtained earlier for the minerals of this chemical type. This is equivalent to 20.5 cubic Ångströms, which is well within the limits of experimental error.

Such evidence is practically conclusive that, for the most part, the water present in these minerals is water of crystallization. The molecular volume of water in ice, 19 plus, compared with Clarke's average of 13.76 in the hydrates, indicates a condensation which in all probability takes place due to the bonding effect of the cation or anion, or both, upon the water molecules. That the water is changed in no other way is indicated

by the fact that infra-red adsorption spectra of compounds such as vivianite show the characteristic water lines, which is not true of the minerals containing water of constitution, which show characteristic (OH) lines.

Without vapor pressure dehydration measurements and *x*-ray diffraction data, it is impossible to state exactly how the water is held; it must suffice to say here that the water present is apparently compositional and can, therefore, serve as a basis of classification into families.

BASIS OF DIVISION INTO GROUPS

The division of the family into groups based upon similarity of crystal symmetry is a standard procedure. The crystallographic relations within the groups will be discussed in the treatment of each family.

It need only be pointed out that in these minerals the number of molecules in the unit cell of the triclinic species is always one, in the monoclinic species, two (in one case there are four), and in the orthorhombic, always four. This is no doubt due to the fact that the higher symmetries are obtained directly from the lower by a twinning of the lattice, a single plane of reflection producing monoclinic symmetry with a double volume and two planes of reflection producing orthorhombic symmetry with a quadruple volume.

SYSTEMATIC TREATMENT OF FAMILIES

$A_3(XO_4)_2 \cdot 2H_2O$ Family

This family contains the two triclinic species, fairfieldite, and collinsite and the two monoclinic species, roselite and brandtite. The unit cells of the triclinic and monoclinic species are simply related, *a* and *c* being practically the same, while *b* is doubled in the monoclinic species. As the monoclinic members are arsenates, and the triclinic members are phosphates, most of the physical properties are appreciably different, but the cell volumes are strictly comparable.

The cell edges are similar or multiples of each other. The composition is only variable within certain limits. The ratio of calcium to the sum of the other cations present in each mineral is approximately 2 to 1. In some cases, the percentage of calcium is somewhat below this, but for the most part the composition might well be written $Ca_2(A)(XO_4)_2 \cdot 2H_2O$, where *A* is Fe, Mn, Mg, or Co; and $(XO)_4$ is $(PO)_4$ or $(AsO)_4$.

This indicates that calcium and the *A* ions occupy non-equivalent positions in the structure. Consequently, only a limited amount of substitution of *A* for Ca is possible. This is in conformity with other experience with calcium-containing minerals such as diopside. This might also

TABLE 3. DATA OF THE $Ca_2(A)(XO_4)_2 \cdot 2H_2O$ FAMILY

Mineral	Collinsite	Fairfieldite	Roselite	Brandite
Composition	$Ca_2(Mg, Fe)(PO_4)_2 \cdot 2H_2O$	$Ca_2(Mn, Fe)(PO_4)_2 \cdot 2H_2O$	$Ca_2(Co, Mg)(AsO_4)_2 \cdot 2H_2O$	$Ca_2Mn(AsO_4)_2 \cdot 2H_2O$
Crystal System	Triclinic	Triclinic	Monoclinic	Monoclinic
Crystal Class	Pinacoidal ?	Pinacoidal	Prismatic	Prismatic
Space Group	$C_4^1 - P\bar{1}$	$C_4^1 - P\bar{1}$	$C_{2h}^6 - P2_1/c$	$C_{2h}^6 - P2_1/c$
a_0	5.70	5.77	5.60	5.65
b_0	6.72	6.56	12.80	12.80
c_0	5.38	5.47	5.60	5.65
$a_0:b_0:c_0$	0.8479:1:0.8002	0.8791:1:0.8331	0.4374:1:0.4374	0.4412:1:0.4412
α	$96^\circ 48\frac{1}{2}'$	$102^\circ 05'$		
β	$107^\circ 16\frac{1}{2}'$	$108^\circ 42\frac{1}{2}'$		
γ	$104^\circ 32'$	$90^\circ 05\frac{1}{2}'$	$100^\circ 45'$	$99^\circ 30'$
Morphology $a:b:c$	Unsatisfactory	Unsatisfactory	0.8780:1:1.4398	0.8720:1:0.4475
Cell Volume	184.46	197.2	394.36	403.00
Cell Contents	1 molecule	1 molecule	2 molecules	2 molecules
Sp. G. Meas.	2.992	3.082	3.695	3.671
Sp. G. Calc.	3.04	3.09	3.645	3.700
Cleavages	(001)(010)	(001)(010)(1\bar{1}0)	(010)	(010)
Hardness	3.5	3.5	3.5	3.5
Optical Sign	+	+	+	+
2V	80°	86°	60°	23°
$r:v$		$r > v$	$r < v$	$r < v$
Indices				
of	α	1.632	pink	dark
Refraction	β	1.642	1.694	1.725
	γ	1.657	1.704	1.728
			1.719	1.735
X		ϕ		
Y		120°	to $[001] 1^\circ$	$[010]$
Z		-102°	to $[010]$	to $[001] 8^\circ$
Locality	Francois Lake	Buckfield	Schneeberg	Pajsberg

be expected because of the appreciably greater ionic radius of calcium compared with the other cations in these minerals.

The (AsO_4) compounds show higher indices of refraction and densities than corresponding (PO_4) compounds. The hardness and cell volumes are not affected by the radical content and are, consequently, approximately constant.

Table 3 summarizes the data on these minerals.

Collinsite.—The original and only description of collinsite was made by Poitevin (1927) on material occurring in phosphorite nodules near François Lake, British Columbia. Included in his description were data on the optical and other physical properties, and the chemistry. As no crystals were found, nothing relative to the crystallography except the angles between the cleavages was given.

The optical and other physical properties listed in Table 3 are those given by Poitevin. The specific gravity, 2.99, measured on the torsion microbalance, however, is slightly higher than the 2.95 given by him.

Poitevin lists four cleavages in the following order of perfection: C_0 , C_1 , C_2 , C_3 , and gives the following angles between them:

$$\begin{aligned} C_0 \text{ to } C_1 &= 88^\circ 40' \\ C_1 \text{ to } C_2 &= 108^\circ 00' \text{ or } 72^\circ 00' \\ C_2 \text{ to } C_3 &= 111^\circ 00' \text{ or } 69^\circ 00' \\ C_1 \text{ to } C_3 &= 131^\circ 00' \text{ or } 49^\circ 00' \end{aligned}$$

With these he makes a faulty comparison with roselite angles, and correlates faces which cannot actually be considered to be the same. He correlates C_2 , C_3 , and C_1 of collinsite with $b(010)$, $m(110)$, and $M(1\bar{1}0)$ of roselite. It is apparent, however, that these faces in roselite form a distinct zone, while there is no possible means of bringing C_2 , C_3 , and C_1 into the same zone. This is clearly shown by Poitevin (1927, p. 6) in his diagram of the optical orientation relative to the cleavages.

The authenticity of these cleavages is questionable. Six apparently homogeneous fibrous crystals were measured by me, and in no case were the angular relations given by Poitevin observed. The only consistent value obtained was an angle of between 75 and 77 degrees between two fair cleavages. This corresponds to the angle between $c(001)$ and $b(010)$, $75^\circ 30'$, derived from x -ray study. This is comparable with the angle of $77^\circ 12'$ between the same cleavage faces of fairfieldite. The optical orientation of collinsite is given by Poitevin on a Fedorov net with the four cleavages noted by him as reference points. The best cleavage, C_0 , is made polar. If the azimuth to C_1 is taken as $0^\circ 00'$, the following orientation angles are obtained from his plot for three principal directions of the indicatrix:

	ϕ	ρ
X	$-50\frac{1}{2}^\circ$	50°
Y	$-173\frac{1}{2}$	58
Z	$72\frac{1}{2}$	58

The value of these figures is doubtful, for they could not be reproduced in this study. Due to the nature of the crystals, it was impossible to obtain a dependable check on the optical orientation, the solution of which will have to await the discovery of better crystals.

Poitevin's formula deduced from an analysis made by E. A. Thompson is $Ca_2(Mg, Fe)(PO_4)_2 \cdot 2\frac{1}{2}H_2O$. Inasmuch as the x -ray study had demonstrated that there could be but one molecule to the unit cell, $2\frac{1}{2}$ molecules of water were apparently out of the question unless the $\frac{1}{2}$ molecule represented a statistical average of zeolitic water present. Another analysis appeared desirable. Two grams of hand picked material, which under the microscope appeared to be better than 99% pure collinsite, were analyzed by F. A. Gonyer. A summary of the chemistry of collinsite is given in Table 4.

It will be noted that, instead of there being an excess of water in this case, there is a deficiency. There are other differences between the analyses, but it is only necessary to point out that the new analysis agrees fairly well with the theoretical composition in column 6 of Table 4, and the mineral can be said to definitely belong to the $Ca_2A(XO_4)_2 \cdot 2H_2O$ family.

The results of the x -ray work are summarized in Table 3. They were obtained from a slender, prismatic fiber of collinsite. Rotation was around the prism axis, which proved to be $a[100]$.

TABLE 4. CHEMISTRY OF COLLINSITE

	1	2	3	4	5	6
P ₂ O ₅	39.83	41.13	41.35	.975	1	41.63
CaO	32.18	32.03	32.20	1.92	2	32.87
MgO	6.34	9.31	9.36	.78	$\frac{2}{3}$	7.91
FeO	6.86	7.31	7.35	.34	$\frac{1}{3}$	7.03
H ₂ O	12.28	9.69	9.74	1.81	2	10.56
Imp.	2.37	0.37				
Total	99.86	99.84	100.00			100.00

1. Analysis by E. A. Thompson.

2. Analysis by F. A. Gonyer.

3. Analysis by F. A. Gonyer recalculated to 100%.

4. Number of oxides in unit cell: volume = 184.46, $d = 2.992$, $M_0 = 334.3$.

5. Theoretical number of oxides: $M_0 = 341.2$.

6. Theoretical composition for $Ca_2(Mg_{2/3}, Fe_{1/3})(PO_4)_2 \cdot 2H_2O$.

Fairfieldite. This mineral was first described by G. J. Brush and E. S. Dana (1879) on material from Branchville, Connecticut. The material was sufficiently good to give a satisfactory analysis and a complete description of the physical properties. The crystallography, according to Dana, was very unsatisfactory. The specific gravity of 3.08, given in Table 3, obtained on the torsion microbalance (all of the specific gravities measured in this work were made on this balance), is somewhat lower than the value of 3.15 given by the original describers but is close to the calculated value of 3.09.

The material used for this study came from Buckfield, Maine. No chemical analysis was made, but powder pictures of this material and of the type material were identical, proving its authenticity. Several crystallized specimens are in the Harvard collection. All of the crystals, however, are highly etched.

I measured 35 crystals, 5 of which were from the type locality; the remainder were from Buckfield. No consistent measurements could be obtained from any of the Branchville material, but all of the Buckfield crystals gave practically the same results.

On every crystal from Buckfield there were three and often four well-defined forms: $c\{001\}$ —perfect cleavage, $b\{010\}$ —good cleavage, $M\{1\bar{1}0\}$ —distinct cleavage, and $P\{\bar{1}\bar{1}1\}$ —highly etched face. The first three gave constant interfacial angles which check well with those calculated from the elements derived from x -ray study, as is seen below:

	Observed Average	Calculated
(010) to (001)	76°46'	77°12'
(010) to (110)	127°48'	127°56½'
(001) to (110)	83°26'	83°39½'

The observed averages given above are of the readings from all of the crystals measured. The fourth form, $P(\bar{1}\bar{1}1)$, gave angular readings which varied as much as 21 degrees and 18 degrees for the ϕ and ρ values, respectively. Its approximate location and the fact that it occurred on every crystal, however, are sufficient reasons for including this form. The reason for the wide variation in readings is the fact that the faces of this form are always extremely etched and never give a well-defined signal.

The average of the measured angles is compared with the calculated angles below:

	Measured	Calculated
(001) to ($\bar{1}\bar{1}1$)	60°	65°55½'
(010) to ($\bar{1}\bar{1}1$)	110	119 52
(110) to ($\bar{1}\bar{1}1$)	102	94 04

Although there are wide discrepancies between measured and calculated values, no other form with simple indices gives as good readings.

The typical development of the Buckfield fairfieldite crystals is shown in Fig. 1. They are often doubly terminated and show no pronounced tendency to have any particular face attached to the matrix.

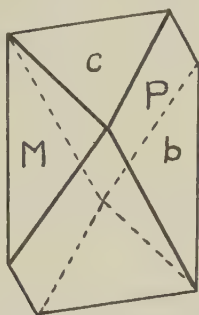


FIG. 1. Fairfieldite from Buckfield.

Table 5 gives the standard angle table and includes, also, the interfacial angle to $M(1\bar{1}0)$. The front pinacoid was not observed on any of these crystals.

TABLE 5. FAIRFIELDITE: ANGLE TABLE

Triclinic—Pinacoidal

$$a:b:c=0.8791:1:0.8331; \alpha=102^\circ 05', \beta=108^\circ 42\frac{1}{2}', \gamma=90^\circ 05'$$

$$p_0:q_0:r_0=0.9266:0.7891:1; \lambda=77^\circ 12', \mu=70^\circ 50', \nu=85^\circ 45'$$

$$p'_0=1.0032, q'_0=0.8543; x'_0=0.3386, y'_0=0.2399$$

Form	ϕ	ρ	A	B	C	M
c 001	$54^\circ 41'$	$22^\circ 32'$	$70^\circ 50'$	$77^\circ 12'$	—	$83^\circ 39\frac{1}{2}'$
b 010	0 00	90 00	85 45	—	$77^\circ 12'$	$127^\circ 56\frac{1}{2}'$
M $1\bar{1}0$	$127^\circ 56\frac{1}{2}'$	90 00	$42^\circ 11\frac{1}{2}'$	$127^\circ 56\frac{1}{2}'$	$83^\circ 39\frac{1}{2}'$	—
P $\bar{1}11$	$-136^\circ 08'$	$43^\circ 41\frac{1}{2}'$	$120^\circ 56\frac{1}{2}'$	$119^\circ 52'$	$65^\circ 55\frac{1}{2}'$	$94^\circ 04'$

Brush and Dana have designated the two cleavages as $b\{010\}$ and $a\{100\}$. These become $c\{001\}$ and $b\{010\}$ respectively, in the new setting. Due to the very imperfect crystals with which Brush and Dana worked, any further correlation must be but approximate. These authors stated exact measurements were quite impossible, and it seems unwise to try to write a transformation formula which, at best, would be but problematical. It seems likely, however, that their (111) is the equivalent of the strongly etched ($\bar{1}\bar{1}1$) face observed by myself.

The optical orientation referred to the setting in the above angle table is:

Index	ϕ	ρ
X	120°	60°
Y	-102°	36°
Z	18°	69°

This is in essential agreement with that worked out by Berman (1930) on fairfieldite from Poland.

Rotation, 0-layer-line, and 1-layer-line pictures were taken about the [001], [100], and [110] axes. From these the x -ray data given in Table 3 and the elements in Table 5 were calculated. There is no need to review these calculations here. It is sufficient to point to the excellent agreement between the calculated (3.09) and measured (3.08) specific gravities given in Table 3.

Roselite and Brandtite. These two minerals are considered together here because my x -ray work has proven them to be isostructural, since there is practical coincidence of position and intensities for all spots on the x -ray pictures.

Similarities and differences between these minerals are shown in Table 3. Differences in optical behavior and specific gravity are easily explained by the differences in composition, the magnesium in the roselite tending to lower the indices of refraction and the specific gravity. It will be noted that two sets of optical data are given for roselite. These are for the "pink" and for the "rose" varieties. The variation in optics, density, and color in the two varieties is, likewise, due to the degree of predominance of magnesium. X-ray powder pictures of both varieties are identical. For this reason it was not considered necessary to do the Weissenberg work on more than the "pink" one. The amount of magnesium present is insufficient to affect the x -ray diffraction results.

Aminoff (1919) showed that earlier designations of brandtite as triclinic were in error and made a thorough study of the crystallography, proving the monoclinic symmetry. Later, Peacock (1936) did the same for roselite without cognizance of Aminoff's earlier work on brandtite and obtained strictly comparable results.

No further work on the crystallography of these minerals is necessary except that a transformation formula from the double cells of Aminoff and Peacock must be given. The a -axis of the unit cell is but half of that given by these earlier workers. The x -ray pictures of both minerals were excellent, and there seems to be no chance that any halving could have been missed. The transformation formula, then, from Aminoff and Peacock to the structural cell is: $\frac{1}{2}00/010/001$.

The x -ray work on roselite consisted of rotation, 0-layer-line, and 1-layer-line pictures about the $b[010]$ axis, and rotation and 0-layer-line pictures about the $c[001]$ axis. A similar set of pictures was taken for brandtite. Peacock noted in his work the almost universal occurrence of twinning in roselite on $a(100)$. An apparently single, homogeneous crystal was used for the x -ray work, but the 0-layer-line and 1-layer-line pictures about $b[010]$ showed twinning. This twinning was indicated by two in-

terpenetrating lattices with approximate coincidence of one-third of the diffraction spots, which explains the frequency of the twinning. In spite of the halving of the a -axis, the index of the twin according to the Friedel method of interpretation remains 3 as stated by Peacock (1936). This is due to the presence of a node of the simple lattice in the center of the multiple, pseudo-orthorhombic cell.

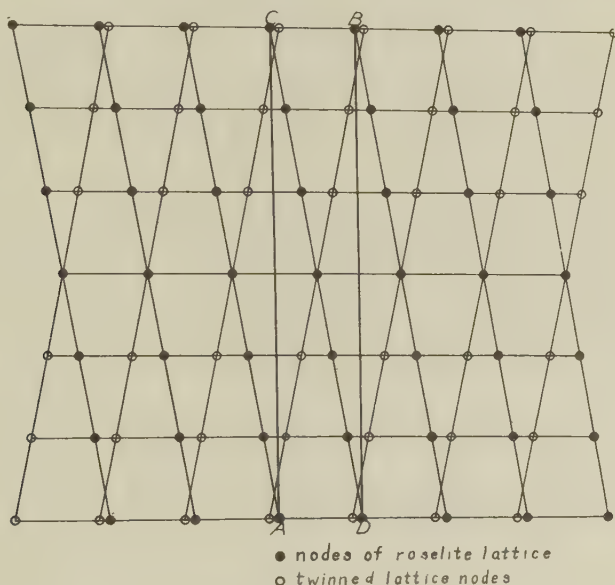


FIG. 2. Twinned lattices of roselite.

Figure 2 shows such a projection with the interpenetrating lattices. That there is an approximate, periodic duplication of the spots in both lattices is apparent. There seems no reason to doubt that it is this duplication which is the physical basis for the twinning. A similar phenomenon was noted in symplectite, which, though triclinic, simulates monoclinic symmetry by a similar twinning of the lattice. An orthorhombic symmetry is simulated in roselite through the twinning of the lattice, as is well shown in Figure 2 by the parallelogram $ABCD$.

The space group is fixed by the following determinative reflections, plus the fact that the crystals are holohedral:

hkl —all present
 $h0l$ — l , even
 $0kl$ — k , even

Chemically, roselite and brandtite are essentially $Ca_2A(XO_4)_2 \cdot 2H_2O$ compounds. A in roselite is equivalent to cobalt and magnesium in vary-

ing proportions. As has already been pointed out, the varying amounts of these two are the controlling factors in color, density, and optical variations which have been noted for roselite. The calculated specific gravity given for roselite in Table 3 was derived for a cell containing $\text{Ca}_4\text{CoMg}(\text{AsO}_4)_4 \cdot 4\text{H}_2\text{O}$, which is practically the formula obtainable from Winkler's (1877) analysis, the only satisfactory one that has been made of the mineral. The measured specific gravity was made on the "dark rose" variety, which unquestionably carries more cobalt than that in the generalized formula used for calculating the specific gravity. This probably accounts for the discrepancy in values. Specific gravity determinations of the "pink" variety were unreliable due to insufficiently large and homogeneous samples.

A in the brandtite formula is essentially manganese. The calculated specific gravity for brandtite given in Table 3 was derived for a cell containing two molecules of $\text{CaMn}(\text{AsO}_4)_2 \cdot 2\text{H}_2\text{O}$, which is essentially correct for the analysis made by Lindström (1891).

The slightly larger cell of brandtite is in keeping with the presence of manganese, which has a larger ionic radius than either cobalt or magnesium.

Dana (1892) gives the hardness for brandtite as 5–5.5, which is much greater than the 3.5 of the other minerals of this family. In checking, I found that brandtite would scratch calcite and would not scratch fluorite, making the actual hardness about 3.5.

$\text{A}_3(\text{XO}_4)_2 \cdot 3\text{H}_2\text{O}$ FAMILY

Reddingite. $(\text{Mn}_{3/4}\text{Fe}_{1/4})_3(\text{PO}_4)_2 \cdot 3\text{H}_2\text{O}$. Only one member of this family has thus far been found. This is reddingite with the composition $(\text{Mn}_{3/4}, \text{Fe}_{1/4})_3(\text{PO}_4)_2 \cdot 3\text{H}_2\text{O}$. There are four of these molecules to the unit cell, yielding $\text{Mn}, \text{Fe}_3(\text{PO}_4)_8 \cdot 12\text{H}_2\text{O}$. This is obtained from the analysis by Gonyer in Berman and Gonyer (1930) on material from Poland, Maine; the same material was used in the *x*-ray investigation.

X-ray data were obtained from rotation, 0-layer-line, and 1-layer-line pictures with [010] as the rotation axis, and rotation and 0-layer-line pictures with [100] as the rotation axis. The space group criteria are:

- hkl —all present
- $Ok\bar{l}$ —all present
- $h0l$ —with $h+l$, even
- $hk0$ —with h , even

The mineral is orthorhombic-dipyramidal, and the space group is $D_{2h}^7 - Pmna$. Hopeite is the only other orthorhombic mineral in the chemical type. Its space group is $D_{2h}^{16} - Pnma$.

The results of the study of reddingite are given in Table 6. The specific

gravity seems to disagree with the general principle that the density should become lower with a higher water content. There is no ambiguity in this case, however, for the cations are iron and manganese, while in the "2H₂O" family the cation weight was composed principally of the much lighter calcium ion.

TABLE 6. DATA OF THE $A_3(XO_4)_2 \cdot 3H_2O$ FAMILY

Mineral	Reddingite
Composition	$(Mn_{3/4}Fe_{1/4})_3(PO_4)_2 \cdot 3H_2O$
Crystal System	Orthorhombic
Crystal Class	Dipyramidal
Space Group	$D_{2h}^{17}-Pmna$
a_0	9.52
b_0	10.06
c_0	8.70
$a_0:b_0:c_0$	0.9463:1:0.8648
Morphology $a:b:c$	0.9428:1:0.8622
Cell Volume	833.2
Cell Contents	4 molecules
Sp. G. Meas.	3.22
Sp. G. Calc.	3.244
Cleavage	{010} poor
Hardness	3-3.5
Optical Sign	+
2V	65°
$r:v$	$r > v$ perc.
Indices of Refraction	$\left\{ \begin{array}{l} \alpha \\ \beta \\ \gamma \end{array} \right\} \begin{array}{l} 1.655 \\ 1.662 \\ 1.683 \end{array} \begin{array}{l} \text{variable} \\ \text{with} \\ \text{composition} \end{array}$
X	c
Y	b
Z	a
Locality	Poland, Maine

(Part 2 to follow in next issue)

CRYSTALLOGRAPHY OF ULEXITE

JOSEPH MURDOCH, *University of California at Los Angeles.*

HISTORICAL

Ulexite has been known since about 1840, but only as the fine fibers known as "cotton-ball," or more recently as massive prismatic aggregates, but never in definite crystals. Accordingly, little has been known of its crystal character. Hintze¹ states that it is possibly monoclinic, but says that nothing definite is known of its crystallography. The suggestion of monoclinic symmetry is based on the work of Buttgenbach,² who studied minute flakes under the microscope. The flakes were sometimes bounded by edges making angles of 45° and 70° with their elongation. Assuming these edges to represent faces normal to the flakes, he suggested that the mineral may occur in crystals which are platy parallel to (010), and bounded by a monoclinic combination of (100) (101) ($\bar{1}$ 03). Other flakes were nearly rectangular in outline, and suggested orthorhombic symmetry. He determined extinction as always parallel to the elongation, which was positive. This agrees with Des Cloizeaux,³ who considered the extinction as nearly or exactly parallel to elongation. Larsen and Berman⁴ made the following determinations of optical properties: Biaxial positive; indices, $\alpha = 1.491$, $\beta = 1.504$, $\gamma = 1.520$; $X = b$; $Y \wedge c = 23^\circ - 0^\circ$; $2V$ moderate. They give the specific gravity as 1.65 and hardness = 1, (erroneous, because determined on "cotton-ball"). Foshag⁵ found massive fibrous material at Lang, California, and gives an analysis of it. Schaller,⁶ with similar material from the Kramer district of California, determined indices in close agreement with Larsen and Berman. He found Y to be approximately parallel to the elongation, the angle $Y \wedge c$ variable, and about 20°. Elongation was usually negative, though occasionally positive. His material showed universal and intimate polysynthetic twinning parallel to the elongation. Specific gravity of this massive material is 1.963, a much more accurate value than could be ob-

¹ Hintze, Carl, *Handbuch der Mineralogie*. Erst. Band, Viert. Abt., erste Hälfte, 156-167.

² Buttgenbach, H., The borate deposits of Salinas Grandes, Argentina: *Ann. Soc. Geol. Belgique*, **28**, mem. 99 (1900-1901).

³ Des Cloizeaux, A., *Manuel de Minéralogie*, **2**, 10 (1874).

⁴ Larsen, Esper S., and Berman, Harry, The Microscopic Determination of the Non-opaque Minerals: *U.S.G.S., Bull.* **848**, 99 (1934).

⁵ Foshag, W. F., The origin of the colemanite deposits of California: *Econ. Geol.* **16**, 204 (1921).

⁶ Schaller, W. T., Borate minerals from the Kramer district, Mohave desert, California: *U.S.G.S., Prof. Paper* **158-I**, 139 (1930).

tained from the "cotton-ball." Many reliable chemical analyses have fixed the chemical composition as $\text{NaCaB}_5\text{O}_9 \cdot 8\text{H}_2\text{O}$.

OCCURRENCE

The writer recently had the good fortune to discover measurable crystals of ulexite, and to work out their crystallography. Identification of the mineral was by means of indices of refraction, which agreed closely with published values, and by a confirmatory chemical analysis.

The material studied was collected from the waste dump of the new shaft of the Suckow Borax Mine, in the Kramer district, San Bernardino County, California. It consists of three or four small hand specimens, which were taken because of their leached and crystalline appearance. Close examination showed them to be made up largely of white or transparent ulexite in a matrix of clay and borax. Exposure to the elements had resulted in the weathering away of some of this matrix, partially exposing the crystals to view. The ulexite occurs as massive aggregates of crystalline grains, sub-parallel or divergent, with occasional regions in which the individuals are more or less completely separated, and irregularly distributed in the matrix. Some of these separate crystals are more or less completely terminated and can be readily detached for study. Other crystals were obtained by careful leaching and washing away of the matrix, many of the individuals thus separated being excellent for crystallographic measurement. There is a frequent tendency, especially in the case of the larger ones, for these crystals to be partially hollow, due to the inclusion, and subsequent dissolving away, of small grains of borax. In such crystals, terminal faces are absent, or appear as narrow faces surrounding the pitted ends.

Most of the crystals are only a fraction of a millimeter in length, although they may reach a maximum of 5-6 millimeters. The larger crystals are usually incomplete, or with no terminal faces, but a large proportion of the smaller individuals are well formed. In general, they are rather slender, elongated, with six or eight faces in the prism zone, and with from three to six terminal faces. About half of the crystals studied were flattened parallel to (100), and the others were more or less equidimensional or diamond shaped in the direction of elongation.

It is interesting to note that the ulexite crystals in the hand specimen appear to remain clear and glassy for an indefinite period, but that crystals isolated and mounted for study become roughened and whitened in the course of a month or so, even when kept in a stoppered vial. This behavior is disappointing, as such crystals soon become unmeasurable, and so are not available for re-examination.

PHYSICAL AND OPTICAL PROPERTIES

Ulexite in crystals is transparent and colorless, with vitreous luster. It is brittle, with a hardness just over 2.5, since it scratches halite with difficulty. The specific gravity, as determined on a pure fragment by both Dr. Harry Berman and the writer, on the torsion micro-balance,⁷ is $1.955 \pm .001$. This checks very closely with Schaller's value of 1.963 on massive material, and with the calculated value of 2.001 from x-ray data. There are two good cleavages and one poor one in the prism zone, and a direction of easy fracture nearly perpendicular to it. One very perfect cleavage is parallel to (010), and was oriented by splitting a measured crystal with a needle, and determining the position of the cleavage face with respect to known crystallographic directions. Another cleavage, not quite so good, is parallel to (1 $\bar{1}$ 0), and was located in the same way. The third cleavage in the prism zone, parallel to (110) was determined under the microscope only, and was not observed on the goniometer. It is rather poor. The cross fracture shows on nearly every prism fragment, but is too uneven to be considered a cleavage.

Twinning is rare in the separate crystals, but rather common in the aggregates. It is quite varied, a number of twin planes being measured. The following are fairly well determined: (010), (100); less positively (3 $\bar{4}$ 0) or (2 $\bar{3}$ 0); in addition a number of planes were observed apparently bearing no very simple relationship to the axes, but approaching in position such faces as (2 $\bar{3}$ 1), (011), or (0 $\bar{7}$ 1).

Optically, the biaxial positive character and recorded indices of refraction are confirmed. Elongation is positive, and the maximum extinction angle from the prism is $21\frac{1}{2}^\circ$. The optical orientation of the mineral was determined on the universal stage, and checked for the writer by Dr. James Gilluly. $2V = 73^\circ \pm 1^\circ$; $Y \wedge c = 21\frac{1}{2}^\circ$. The stereogram of this orientation is shown in Fig. 1.

An analysis of selected material from the Suckow locality as compared with the theoretical values, and with analyses by Foshag and Schaller, is given below.

	1	2	3	4
CaO	13.85	13.92	14.14	14.06
Na ₂ O	7.65	7.78	7.06	7.09
B ₂ O ₃	42.95	43.07	43.12	42.94
H ₂ O	35.55	35.34	35.68	35.54
insol.	—	—	—	0.10

(1) Theoretical; (2) Suckow, F. A. Conyer; (3) Lang, W. F. Foshag; (4) Kramer, W. T. Schaller.

⁷ Berman, Harry, A torsion micro-balance for the determination of specific gravities of minerals: *Am. Mineral.*, **24**, 434-440 (1939).

CRYSTALLOGRAPHY

Ulexite is triclinic, probably holohedral, occurring ordinarily in prisms elongated parallel to c . Usually only unit forms are present, but one or two crystals were observed showing more complex faces. Thirty-nine crystals were measured, and more examined under the binocular. No visibly twinned crystals were seen among those measured or examined,

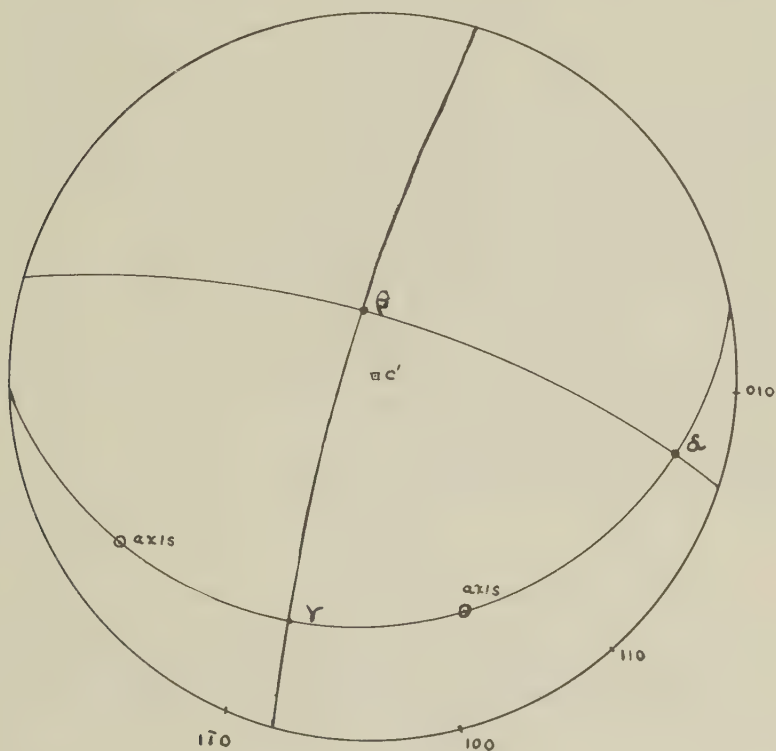


FIG. 1

although twinning was noted in the massive material. No doubly terminated crystals were observed, but of those measured, 23 were upper terminations, and 16 were lower, and there was no appreciable difference in the percentage frequency of terminal faces on the two ends.

Orientation

Orientation of the crystals was determined from the gnomonic projection by using the normal setting for triclinic crystals advocated by Peacock,⁸ in which (001) lies to the right and forward of the center, and a is shorter than b . It so happens that in this setting the positive pyra-

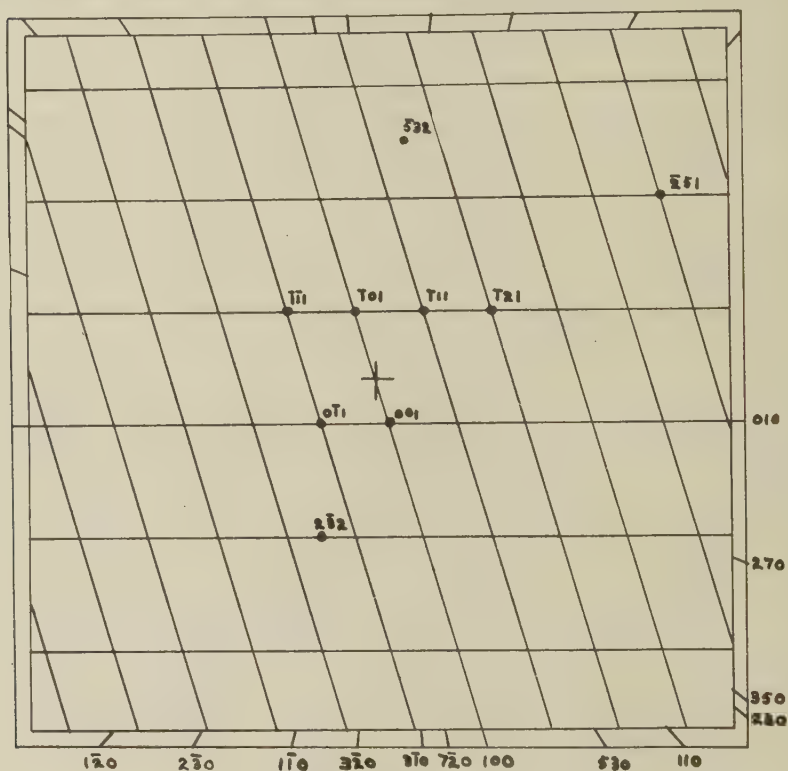


FIG. 2

mids are absent, but the position is analogous to the revised setting of meyerhofferite described by Palache⁹ which has the dominant faces in the rear octants.

⁸ Peacock, M. A., On the crystallography of axinite and the normal setting of triclinic minerals: *Am. Mineral.*, **22**, 592-593 (1937).

⁹ Palache, Charles, Crystallography of meyerhofferite: *Am. Mineral.*, **23**, 644-648 (1938).

Forms

The forms present are as follows, those within the brackets are uncommon: c (001), b (010), a (100), m (110), M ($\bar{1}\bar{1}0$), s ($0\bar{1}1$), o ($\bar{1}01$), t ($\bar{1}11$), p ($\bar{1}\bar{1}1$), d ($\bar{1}21$) [z , ($2\bar{3}2$) x ($\bar{5}32$) q ($\bar{2}51$), l (270) h (350), k (230), r (530) L (720), N ($3\bar{1}0$), R ($3\bar{2}0$), K ($2\bar{3}0$), H ($\bar{1}20$)].

Figure 2 shows the gnomonic projection of these forms.

Calculation of elements

The axial ratio is: $a:b:c=0.6855:1:0.5191$.

The axial angles are: $\alpha=90^{\circ}16'$; $\beta=109^{\circ}08'$; $\gamma=105^{\circ}07'$.

These elements were derived from the average measurements of ϕ and ρ for eight commonly appearing forms. For these averages, only faces giving good signals were used, but many other readings, with poorer signals, agree very closely with them. X-ray oscillation photographs were taken about the axis of elongation, and showed no plane of symmetry, thus confirming the triclinic character of the mineral. The length of the vertical edge of a possible unit cell was measured directly from the spacing of the layer lines in the photographs. The other dimensions were calculated from the x-ray data using the morphologic axial angles. The values are as follows: $a_0=8.71\text{\AA}$, $b_0=12.72\text{\AA}$, $c_0=6.69\text{\AA}$. Recalculated to $b=1$ these values give $a:b:c=0.6856:1:0.5256$, which agree very closely with the crystallographic measurements. The unit cell apparently contains two molecules, as the density calculated on this basis, is 2.001, agreeing very closely with the observed value of 1.955.

Description of Forms

In general, the larger terminal faces are ($\bar{1}\bar{1}1$) and ($0\bar{1}1$), with (001) ($\bar{1}01$) and ($\bar{1}11$) quite small, so that the crystals have a distinctly oblique end, and a monoclinic aspect. In the prism zone, (100) is nearly always dominant, and frequently has a somewhat irregular surface. The prisms (110) and ($1\bar{1}0$) are about equally well developed, narrower than (100) and nearly always smooth and glassy. (010) is generally quite subordinate, and practically always the narrowest face in the zone, sometimes appearing only as a line-face. This combination produces the characteristic lathlike appearance of many crystals, which are ordinarily rather slender. There are sometimes variations from these proportions, so that the crystals become more nearly equidimensional prisms, but the length is always at least 2 to 3 times the next longest dimension, and frequently much more. Some of the commoner types of terminations are shown in the drawings (Figs. 3-5). No one type is predominant among the crystals studied. The wide variation in terminal combinations is shown in the table on page 760, which includes 27 completely terminated crystals.

and it may perhaps be an interference surface, not a true crystal face. Crystal #24 shows an unusual combination of prism faces in addition to the ordinary. These are as follows: (530), ($\bar{3}50$), ($\bar{7}20$), (230), ($\bar{3}20$), all narrow with poor signals; ($\bar{3}20$) narrow but fair signal; (130), ($\bar{7}20$) average of poor double signals; (120) best of poor triple signal. They may be considered as very doubtful forms. This same crystal also has an unusual combination of terminal faces. They are (001) and ($0\bar{1}1$), both small, with ($\bar{5}32$), a large face with good signal, not observed on any other crystal. Poorly developed, narrow faces in the prism zone also occur on three other crystals. Crystal #1, ($\bar{3}10$). #15 (230), #34 (530). (230) and (350) do not occur on the same crystal and probably represent poor positions for the same form. The same is true for ($\bar{7}20$) and ($\bar{3}10$).

It might be interesting to see how the forms and cleavage as observed might fit in with Buttgenbach's microscopic determinations. For instance, his monoclinic form might be duplicated by assuming a cleavage flake on ($1\bar{1}0$) bounded by $\bar{1}21$, with the ρ angle near 45° , and ($0\bar{1}1$), with ρ near 20° . The cleavage lines in the section would then be the (010) cleavage. The other might well be a cleavage flake bounded by the prism faces and the nearly horizontal cross fracture.

TABLE 2. ANGLE TABLE

For reference, the complete angle table for ulexite calculated in the conventional form, is given below.

Triclinic Pinacoidal $C_2^1-P\bar{1}$

$a:b:c=0.6855:1:0.5191$

$\alpha=90^\circ16'$ $\beta=109^\circ08'$ $\gamma=105^\circ07'$

$p_0:q_0:r_0$ 0.7852:0.5080:1

$\lambda=84^\circ20\frac{1}{2}'$ $\mu=70^\circ05\frac{1}{2}'$ $\nu=73^\circ53\frac{1}{2}'$

$p_0'=0.8351$ $q_0'=0.5403$ $x_0'=0.3466$ $y_0'=0.1048$

Form	ϕ	ρ	A	B	C
<i>c</i> (001)	$73^\circ10'$	$19^\circ54\frac{1}{2}'$	$70^\circ05\frac{1}{2}'$	$84^\circ20\frac{1}{2}'$	$0^\circ00'$
<i>b</i> (010)	$0^\circ00'$	$90^\circ00'$	$73^\circ53\frac{1}{2}'$	$0^\circ00'$	$84^\circ20\frac{1}{2}'$
<i>a</i> (100)	$73^\circ53\frac{1}{2}'$	$90^\circ00'$	$0^\circ00'$	$73^\circ53\frac{1}{2}'$	$70^\circ05\frac{1}{2}'$
<i>l</i> (270)	$20^\circ42'$	$90^\circ00'$	$53^\circ11\frac{1}{2}'$	$20^\circ42'$	$78^\circ18'$
<i>h</i> (350)	$35^\circ19'$	$90^\circ00'$	$38^\circ34\frac{1}{2}'$	$35^\circ19'$	$74^\circ24'$
<i>k</i> (230)	$37^\circ35'$	$90^\circ00'$	$36^\circ18\frac{1}{2}'$	$37^\circ35'$	$73^\circ53'$
<i>m</i> (110)	$46^\circ05\frac{1}{2}'$	$90^\circ00'$	$27^\circ48'$	$46^\circ05\frac{1}{2}'$	$72^\circ21'$
<i>r</i> (530)	$55^\circ12\frac{1}{2}'$	$90^\circ00'$	$18^\circ41'$	$55^\circ12\frac{1}{2}'$	$71^\circ20'$
<i>L</i> ($\bar{7}20$)	$84^\circ28\frac{1}{2}'$	$90^\circ00'$	$9^\circ13\frac{1}{2}'$	$84^\circ28\frac{1}{2}'$	$70^\circ28'$
<i>N</i> ($\bar{3}10$)	$86^\circ19'$	$90^\circ00'$	$12^\circ25\frac{1}{2}'$	$86^\circ19'$	$70^\circ43'$
<i>R</i> ($\bar{3}20$)	$99^\circ05'$	$90^\circ00'$	$25^\circ11\frac{1}{2}'$	$99^\circ05'$	$72^\circ10'$
<i>M</i> ($1\bar{1}0$)	$111^\circ02'$	$90^\circ00'$	$37^\circ08\frac{1}{2}'$	$111^\circ02'$	$74^\circ23'$
<i>K</i> ($\bar{2}30$)	$125^\circ48'$	$90^\circ00'$	$51^\circ52\frac{1}{2}'$	$125^\circ48'$	$78^\circ04'$
<i>H</i> (120)	$136^\circ37'$	$90^\circ00'$	$62^\circ43\frac{1}{2}'$	$136^\circ37'$	$81^\circ15'$
<i>s</i> ($0\bar{1}1$)	$141^\circ29\frac{1}{2}'$	$29^\circ06'$	$79^\circ19'$	$112^\circ22\frac{1}{2}'$	$28^\circ09'$
<i>o</i> ($\bar{1}01$)	$-105^\circ35'$	$25^\circ19'$	$115^\circ15'$	$96^\circ33'$	$45^\circ13\frac{1}{2}'$
<i>i</i> ($\bar{1}11$)	$-47^\circ47\frac{1}{2}'$	$31^\circ36'$	$105^\circ58\frac{1}{2}'$	$69^\circ23'$	$45^\circ09\frac{1}{2}'$
<i>p</i> ($\bar{1}\bar{1}1$)	$-145^\circ41'$	$38^\circ57'$	$118^\circ59'$	$121^\circ17'$	$55^\circ38'$
<i>d</i> ($\bar{1}21$)	$-25^\circ32\frac{1}{2}'$	$46^\circ35'$	$96^\circ50\frac{1}{2}'$	$49^\circ03'$	$52^\circ29\frac{1}{2}'$
<i>z</i> ($\bar{2}32$)	$112^\circ52'$	$51^\circ16'$	$52^\circ40'$	$107^\circ39'$	$37^\circ33\frac{1}{2}'$
<i>x</i> ($\bar{5}32$)	$-78^\circ34'$	$59^\circ25\frac{1}{2}'$	$139^\circ46'$	$80^\circ10'$	$77^\circ16\frac{1}{2}'$
<i>q</i> ($\bar{2}51$)	$-28^\circ14'$	$69^\circ23\frac{1}{2}'$	$101^\circ36\frac{1}{2}'$	$34^\circ27'$	$74^\circ27\frac{1}{2}'$

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The chemical analysis was made possible by a grant from the Research Fund of the University of California.

NOTES AND NEWS

EQUIPMENT FOR THE DOUBLE VARIATION METHOD OF REFRACTIVE INDEX DETERMINATION

I. AN IMPROVED STAGE CELL

II. VARIABLE TEMPERATURE CONTROL APPARATUS

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ABSTRACT

I. The cell used in the double variation method has been modified by placing the inlet and outlet channels on opposite ends of an elliptical cell, thereby eliminating the trapping of air-bubbles and reducing to a minimum the turbulence of the water flowing through the cell.

II. A convenient apparatus has been devised to provide hot and cold water at a constant pressure used in the production of any desired temperature in the double variation apparatus. By heating electrically a constant flow of cold water, it is possible to provide a supply of water maintained at an approximately constant temperature of fifty degrees Centigrade.

I. AN IMPROVED STAGE CELL

The operation of the ordinary form of cell^{1,2} used in the double variation method of refractive index determination is marred by considerable turbulence of the water flow and the spinning around of air-bubbles in the center of the cell, which usually is also in the field of the microscope. These annoying air-bubbles may be removed by momentarily shutting off the water, but they soon reappear and obscure the field.

The author wishes to describe a modified form of cell, which eliminates the air-bubbles and reduces the turbulence of the flowing water. The new cell is illustrated in Fig. 1 and may be compared with the original Emmons cell shown in Fig. 2.

The cell consists of two brass plates of the specified dimensions separated by a cork composition gasket, which not only determines the thickness of the water compartment but also its shape. The circular opening in each plate is closed by sealing a cover glass on the inside of the plate in a prepared seat with hard Dekhotinsky cement. The plates are fastened together by means of six screws which, by tightening, prevent any leakage from the cell. The inlet and outlet tubes enter the top plate at either end of the elliptical cell produced by the cut-out gasket. The water entering this cell flows in a thin sheet between the two cover

¹ Emmons, R. C., *Am. Mineral.*, **13**, 504 (1928).

² Emmons, R. C., *Am. Mineral.*, **14**, 414 (1929).

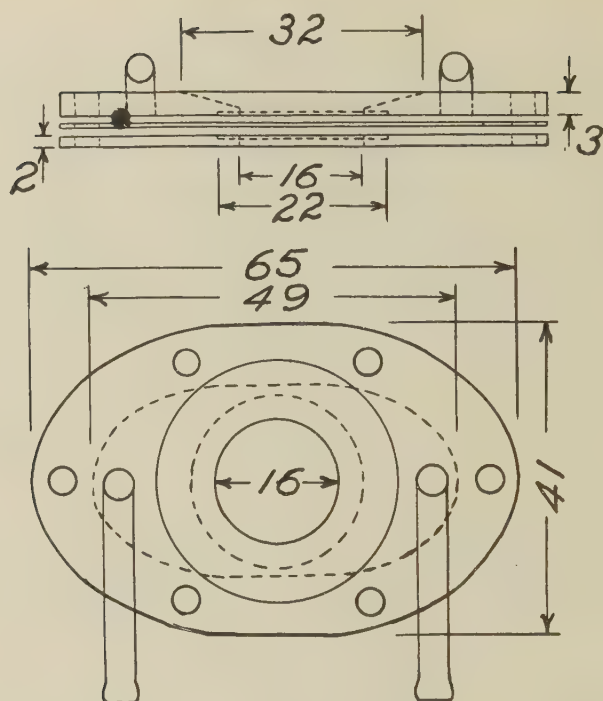


FIG. 1. Improved Stage Cell.
(Dimensions in Millimeters)

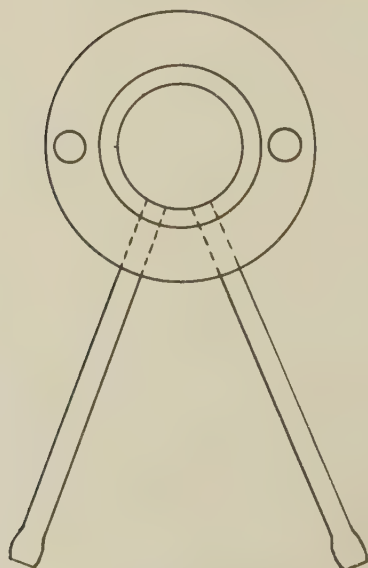


FIG. 2. Emmons Stage Cell.

glasses and out at the other end without turbulence due to irregular surfaces, while air-bubbles pass through with the flowing water and are not trapped in eddies or circular flow. The top plate is bevelled for some distance around the cover glass to render the latter more accessible for the preparation of a mount. The placing of the cover glasses flush with the inner surfaces of the plates reduces turbulence and also makes possible a much thinner cell. If the cell is thin enough, it may be possible to observe interference figures in mineral grains, which would be advantageous for purposes of identification of the mineral or in determining directions of vibration.

II. VARIABLE TEMPERATURE CONTROL APPARATUS

The operation of the double variation apparatus requires a constant supply of hot and cold water. The apparatus described herein was de-

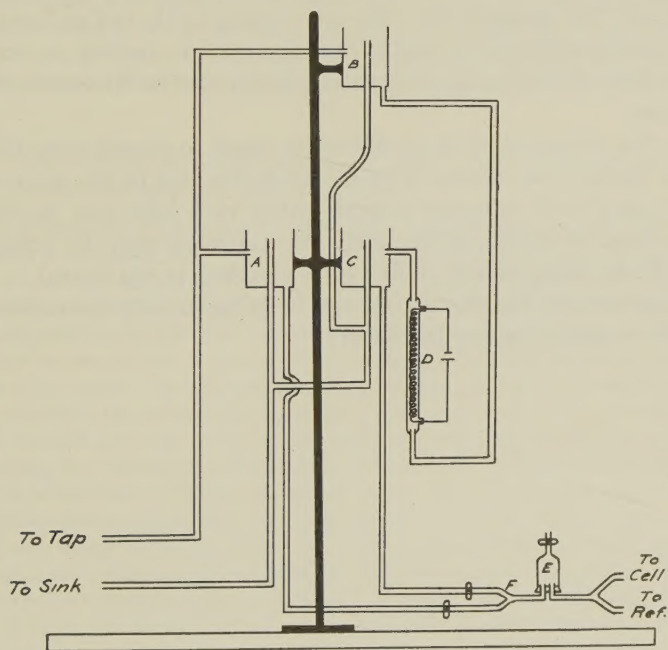


FIG. 3. Variable Temperature Control Apparatus.

vised for this purpose for use in laboratories having no hot water line, or where the hot water supply is unreliable. It has been used to provide constant temperature conditions in refractometric and polarimetric measurements as well as for temperature variation in the double variation method of refractive index determination. Fig. 3 shows a diagrammatic representation of the apparatus.

The copper vessel *A*, having a capacity of approximately 200 ml., is supplied from the cold water line and acts as a constant level vessel providing cold water at constant pressure to the mixing tube *F*. A similar vessel *B*, placed at a higher level, supplies the hot water vessel *C* with water at a constant pressure and approximately constant temperature, maintained by the heater *D*, which consists of a glass tube containing a coil of seven feet of No. 24 B. and S. gauge nichrome wire, connected directly, or through a variable resistance, to the 110 volt direct current supply. The heater, using a current of ten amperes, will raise the temperature of four hundred milliliters of water flowing through in one minute from 20°C. to 50°C. The hot water outlet is connected by means of rubber tubing to the mixing Y-tube *F*. The inlets enter each vessel slightly below the upper level of the over-flow pipes and are bent so as to produce a circular motion of the water with consequently better separation of entrained air. The temperature of the water going to the cell and refractometer is readily adjusted by means of screw clamps applied to each line or by means of easily adjusted valves found on the Bausch and Lomb apparatus.

Since the mixing of hot and cold water tends to release some dissolved gases, a bubble trap *E* should be placed in the line to the water cell. A Gooch funnel with two-hole stopper fitted with inlet and outlet tubes serves as an excellent bubble trap. Air collected may be released by means of the clamp on the rubber tube attached to the funnel.

This apparatus has the advantage of being readily assembled from materials available in any laboratory.

BOOK REVIEWS

MINERAL IDENTIFICATION SIMPLIFIED. A Handbook of the Minerals by ORSINO C. SMITH. Flexible leather binding, 5×7½ in., 271 pages. Wetzel Publishing Co., Inc., Los Angeles, California. 1940. Price \$3.50.

The handbook consists essentially of mineral tables carrying over 2,000 entries. The author states that he has included all minerals that had been reported in the literature up to Jan. 1, 1940. The more common minerals are printed in bold-face type.

The two important physical properties—specific gravity and hardness—are made the basis of the classification. The former yielding 15 groups in which the minerals are arranged in the order of decreasing hardness. However the tables record other properties, such as solubility in HCl, fusibility, color, streak, luster, cleavage, fracture, crystal system, and mean index of refraction, although the method for determining this property is not given.

Supplementary and confirmatory chemical tests, both of the wet and blowpipe type of reactions are listed as checks on the determination by physical means. The tables were compiled for the professional mineralogist and geologist, although it is believed the chemist and many others will find this text helpful in their mineralogical determinative work.

W. F. H.

KEMP'S HANDBOOK OF ROCKS by FRANK F. GROUT, Sixth edition, 300+VIII pages Van Nostrand Company, Inc., 1940. Price \$3.00.

Kemp's Handbook of rocks perpetuates the name of a famous and well loved geologist whose name is still something of a talisman in America. But books grow old even as their authors do, and it is a question whether it is ever advisable to re-publish an old-fashioned textbook after the death of its author. If the editor makes all the changes that are needed to bring the book up to date there will be little left of the original text; yet he must defer to the dead author at least to the extent of retaining the general plan of the work. This puts the editor under a heavy handicap. When Professor Kemp wrote the Handbook in 1896 he decided in the interests of simplicity to omit all reference to the microscopic characters of minerals and rocks; yet he quoted many chemical analyses and gave instructions for computing the mineralogical composition of a rock from its chemical composition. It is difficult to believe that in 1896 it was easier to make a chemical analysis of a rock than to study it under the microscope; it is certainly not true in the year 1940, for there must be a hundred men trained in the use of the petrological microscope for one who is qualified to make a good rock analysis. Nevertheless the editor of the new "Kemp" has felt himself obliged to follow the original plan of the book; he neglects the universally used microscopic method of study but retains and adds to the discussion of chemical analyses. How can a man who has never studied rocks under the microscope be expected to make intelligent use of chemical analyses? The reviewer thinks it would have been better to depart still further from the original plan by omitting the chemical data and substituting some elementary instruction in the use of the polarizing microscope. Surely nobody will maintain in these days that rocks can be adequately described or named without the use of the microscope?

The text has been largely rewritten, and a number of illustrations have been introduced which add considerably to the attractiveness of the volume. The glossary of rock names, which many petrologists found more useful than the text, has disappeared and its place is taken by an 8-page list of names which is too condensed to be really helpful to anybody.

S. J. SHAND

SECOND APPENDIX TO THE CATALOGUE OF METEORITES, with special reference to those represented in the Collection of the British Museum (Natural History) by MAX H. HEY. Printed by order of the Trustees of the British Museum, London. 136 pages. 1940. Price 5 shillings.

The Catalogue of Meteorites was issued in 1923 and the first appendix appeared in 1927. The second appendix includes all meteorites described since the publication of the first appendix up to the end of September 1939. Additions and corrections to a number of entries in the catalogue and the first appendix have been made and the repositories of the major specimens of each fall are indicated, if known.

Since the publication of the first appendix in 1927, specimens representing 91 falls have been added to the collection, of these 53 are stones, 31 irons and 7 stony-irons. The Catalogue and two appendices contain 1,251 fairly well established falls of which 758 are represented in the Museum collection. In addition there are 98 "doubtful" and "paired" falls of which 24 are represented. Although the number of meteorites found is increasing rapidly, the Museum at present contains 60.6% of all known falls with every class of meteorite represented.

W. F. H.

NEW MINERAL NAMES

Ablykite

Pseudopyrophyllite

I. SEDLETZKY, and S. YUSSUPOVA: Argillaceous minerals closely approaching halloysite. *Compt. Rend. (Doklady) Acad. Sci. U.R.S.S.*, **26**, No. 9, 944-947 (1940), 2 figs.

X-ray, thermal, chemical and other analyses of the $<0.2\mu$ fraction of clay from Ablyk, Angren River Valley, Uzbek, indicates a new mineral. This is called *ablykite* and its composition is given as $R''O \cdot 2R_2O_3 \cdot 5SiO_2 \cdot 6H_2O$. A fraction isolated from pyrophyllite from Beresovsk by Loewinson-Lessing had the composition $3(Mg, Ca, Fe)O \cdot 4Al_2O_3 \cdot 9SiO_2 \cdot 8H_2O$. This is called pseudopyrophyllite.

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